ELEMENTS

OF

NATURAL PHILOSOPHY.

LONDON:
Printed by C. Adlard, Bartholomew Close.

ELEMENTS

OF

NATURAL PHILOSOPHY;

BEING AN

EXPERIMENTAL INTRODUCTION

TO THE

STUDY OF THE PHYSICAL SCIENCES.

BY

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LONDON:
JOHN CHURCHILL, PRINCES STREET, SOHO.
MDCCCXXXIX.

"Quicquid enim ex phenomenis non deducitur, hypothesis vocanda est; et hypotheses seu metaphysicæ, seu physicæ, seu qualitatum occultarum, seu mechanicæ, in philosophia experimentali, locum non habent. *In hac philosophia propositiones deducuntur ex phenomenis, et redduntur generales per inductionem.*"

NEWTON. PRINCIP. MATH. PHIL., lib. iii., Schol. Gen.

TO THE

COURT OF EXAMINERS

OF

THE SOCIETY OF APOTHECARIES OF LONDON,

THIS WORK

IS

RESPECTFULLY DEDICATED,

IN HUMBLE, BUT SINCERE ACKNOWLEDGMENT OF THE BENEFITS CONFERRED UPON THE MEDICAL PROFESSION, BY THE IMPROVEMENTS THEY HAVE EFFECTED IN THE EDUCATION OF THE PRACTITIONER OF MEDICINE, AND THE CONSEQUENT HIGHER POSITION WHICH HE OCCUPIES IN SOCIETY.

Guy's Hospital, Oct., 1839.

PREFACE.

THE best apology that can be offered for presenting this volume to public notice, will be found in the reason which suggested its compilation, viz., the absence of any system of physics, sufficiently extended to include all those subjects with which men of education, especially members of a liberal and important profession like that of medicine, ought, and are required, to be familiar with; and at the same time not too diffuse to disgust or weary the student.

To the student of medicine, and chemistry in particular, the want of a concise and yet sufficiently comprehensive work on physics has been long felt; as, without an acquaintance with the physical sciences, his professional education must be considered as far from complete; and, independently of this, a knowledge of the principles of these sciences has long been rendered imperative at the different medical boards, and has constituted an important part of the examination which the candidate for a diploma is called upon to undergo.

The following manual is chiefly intended as a text-book for the student whilst attending lectures on physics, or as preparatory to his entering upon the study of larger, and more elaborate works. With this view it has been written; and as the great difficulty experienced in executing this task has arisen from the necessity of knowing, not what to insert, but what to omit, whenever a doubt has arisen on this point, it has been determined by a reference to the amount of knowledge required of the student, by the different English and Scottish medical boards.

A work of this kind I had long ago projected, in consequence of not being acquainted with any in the English language, to which I could refer the students attending the lectures on physics, annually delivered at Guy's Hospital; although I had hitherto shrunk from the task, hoping that a production, so much required by the medical and general student, would have emanated from some more able writer.

As an apology for the arrangement followed in this volume, it must be observed that utility and extreme simplicity, rather than elegance of style, were sought for, and every other object has been sacrificed to obtain this end. The division into numbered paragraphs was adopted, as every chapter would thus become a kind of running commentary on the others, and would, moreover, facilitate reference to distinct subjects in the Analytic Index.

I regret, as every writer on so extensive a series of subjects must do, the impossibility of doing justice to every labourer in the field of philosophic enquiry, by referring each discovery to its author: as far as this could without circumlocution be effected, it has been done. For discoveries of longer date, as they have become the common property of science, there needs no apology for not in every case mentioning the name of their authors in a strictly elementary work.

I have been greatly indebted to several writers in the French and German languages, for many suggestions and illustrations, of which I have never hesitated to avail myself whenever they appeared to divest any subject of obscurity, or to add to its interest. To the "Précis de Physique" of Biot, the "Eléments de Physique" of Pouillet, the "Traité de Physique" of Hauy, the "Positions de Physique" of Quetelet, and the "Grundriss der Experimental-Physik" of Kastner, I have been peculiarly indebted for several illustrations, some of which have not, I believe, previously appeared in an English dress.

Having thus explained the object and unpretending character of this volume, I trust enough has been said to blunt the edge of criticism, should such, perchance, be levelled against it. The critic himself, I would beg to remind of the celebrated observation of Horace—

> "Sunt delicta quibus non ignovisse velimus,
> Nam neque chorda sonum reddit quam vult manus et mens;
> Nec semper feriet quodcunque minabitur arcus."

Those readers who desire further information on the subjects treated of in this work, and have not the assistance derived from attendance on lectures, may, if only a popular acquaintance with them be required, refer to the very elegant, although as yet unfinished, "Elements of Physics" of Dr. Arnott, or to Sir David Brewster's edition of "Euler's Letters to a German Princess." Those who require a more profound acquaintance with these important subjects, should consult the books referred to in the body of this volume, as well as to the treatises published by the Society for the Diffusion of Useful Knowledge. The series of Essays written by the professors of King's College, London, now in the course of publication, will also furnish most valuable comments on this, and other elementary works.

In the execution of this task, I have experienced but one source of regret, and one which every person engaged in the duties of a laborious profession must feel, when called upon to write on a series of subjects, to a certain extent distinct from his immediate duties, and requiring for their elucidation a much greater amount of time, than his more onerous engagements will allow him to devote to them;—this source of regret arises from the feeling, that a work of this kind had not appeared from the pen of one better fitted to the task, than of him who now offers it to public notice.

Wilmington Square;
October, 1839.

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ERRATA.

The reader is requested to correct the following errata, which have crept into these sheets whilst passing through thê press :

PAGE.
9, *line* 15, *for* one inch, *read* 0·1 inch.
67, — 24, — wheel *w*, *read* wheel W, and let the formula be $P \times W = R \times w$.
109, — 15, — Otlot, *read* Otto.
126, — 2, — infringe, *read* impinge.
133, — 14, — 1500, *read* 15000.
156, — 25, — Opinus, *read* Æpinus.
168, — 18, — crystal, *read* body.
174, — 8, — twelve inches, *read* one inch.
192, — *last*, — ne-, *read* negative.

PAGE.
231, *line* 19, *for* combination, *read* combustion.
273, — 13, — inducted, *read* included.
296, — 16, — lines, *read* hues.
303, — 8, — Y, *read* F.
309, — 4 *from bottom*, *for* positive, *read* partial.
314, *line* 4, *for* the air, *read* will.
350, — 8, — alternately, *read* ultimately.

ADDITIONAL ERRATA.

The author deeply regrets that the following errata should have escaped him, whilst revising the sheets.

PAGE				PAGE			
26, *line* 3,	*for* less,	*read* heavier.		150, *line* 11,	} *for* place,	*read* plane.	
111,	10,	renewed,	removed.	257,	16,		
113,	34,	latter,	former.	174,	25,	positive,	negative.
115,	12,	momentum,	velocity.	333,	22,	1500	15,000.

INTRODUCTORY DISCOURSE.

THE natural phenomena which are incessantly developing themselves on our earth, and in the vast space around us, offer to our view so magnificent a spectacle, that the curiosity of the most listless observer becomes powerfully aroused, and in spite of himself he is compelled, in a greater or less degree, to meditate upon the causes capable of producing such marvellous effects. Scarcely is man emancipated from the trammels which confine the reasoning powers during lisping infancy, ere his childish attention becomes attracted by the objects so lavishly scattered around him by the bounteous hand of nature; he observes with all the energy of his young mind the brilliant constellations bespangling the firmament, and the dim outline of the distant landscape, whilst the less striking, but to him equally important, the abstract properties of matter, force themselves on his maturer understanding: the weight of all surrounding bodies—the rippling of the village brook, or roaring of the torrent—the summer's breeze, or wintry hurricane—alike attract his notice; and, from the brilliant vault of heaven to the surface of his own terraqueous habitation, he culls food for meditation, and finds everywhere infinite sources of wonder and delight. But, in the midst of the vast range of natural effects, it is not given to his intellectual faculties to acquire at once a knowledge of the causes producing them, nor to grasp by one bold effort of the mind a comprehension of the laws which these phenomena obey. By slow degrees has this knowledge been acquired; and even now, notwithstanding the number of zealous and devoted laborers in the field of natural science—notwithstanding the accumulated experience of ages, is this knowledge, on many and very important points, deficient. This, however, so far from daunting the student at the outset of his career, should hold out a great attraction to him; urging his exertions in the cause of science, by the prospect it extends of reward in the achievement of some grand discovery, which may, perchance, place *his* in that bright galaxy of names that has adorned science, and be transmitted to an admiring posterity by the side of a Bacon, a Franklin, a Herschel, or a Davy.

Few things are more interesting than to trace the history of the development of the efforts of the human mind, from the earliest dawn of infant science in the records of past times, through the depressing gloom of the lurid and superstitious era of the dark ages, when science was denounced as a crime, and a Bacon, and a Galileo for being its successful cultivators, subjected to the thraldom of the inquisition, up to our own brighter and happier days, when philosophy and the allied branches of knowledge are recognized as objects of the first importance, the man of science respected, and his acquirements appreciated. What singular and diversified opinions do we not meet with upon record concerning the properties of bodies and their component elements; upon the principles and forces which act on inert matter, and maintain the harmony of the universe. What mazes of hypothesis and errors shall we not find!—what a deep mist of confusion!—in the midst of which are scattered a few truths, the offsprings of earlier talents, like stars, rendering more intense by contrast the darkness of the veil of ignorance and error, obscuring what little was known of Nature's laws. Well has it been said, by a talented writer of the present day, that it is "a condition of our race, that we must ever wade through error in our advance towards truth; and it may even be said, that in many cases we exhaust every variety of error before we attain the desired goal. But truths reached by such a course are always most highly to be valued; and when, in addition to this, they may have been exposed to every variety of attack, which splendid talents quickened into energy by the keen perception of personal interests can suggest; when they have revived un-dying from the gloom of unmerited neglect; when the anathema of spiritual, and the arm of secular power have been found as impotent in suppressing, as their arguments were in refuting, them—then they are indeed irresistible. Thus tried, and thus triumphant, in the fiercest warfare of intellectual strife, even the temporary interests and furious passions which urged on the contest have contributed in no small measure to establish their value, and thus to render these truths the permanent heritage of our race. Viewed in this light, the propagation of error, although it may be unfavorable or fatal to the temporary interests of an individual, can never be long injurious to the cause of truth. It may, at a particular time retard its progress for a while, but it repays the transitory injury by a benefit as permanent as the duration of the truth to which it was opposed!"*

Under the general term of Natural Philosophy is comprehended so vast a range of enquiry, that some division of labour becomes necessary, not only for the teacher but the student. Some of the sciences included under this title are so absolutely necessary to the ordinary duties of civilized life, that they form an important part of early education. The properties of numbers, including ordinary, logarithmic, and algebraic arithmetic, a general outline of the arrangements of the universe, comprehending astronomy and geography, with mathematics and geometry, fall under this

* Babbage, Bridgewater Treatise, p. 28.

head, and now constitute a part of the acquirements of every well-educated member of society. Divested of these sciences, Natural Philosophy may be divided, 1st, into the knowledge of the arrangements of the strata composing our globe, and of the remains of the extinct and wonderful inhabitants of the primeval world, forming the sciences of geology and physical geography; 2dly, into the study of the effects resulting from the action of atoms of different forms of matter on each other, constituting the splendid and comprehensive science of chemistry; and, 3dly, into an investigation of the constitution of masses of matter, the laws governing them, and the mutual action of different atoms of the *same* kind; with an examination of the relation they bear to space, and to the various members of the universe, comprehending the study of physics.*

The latter vast and beautiful range of enquiry is that which we are now to commence the investigation of, whose laws we are to study, and whose effects we must endeavour to appreciate. It is scarcely necessary to state, that a general acquaintance with the principles of this portion of natural knowledge is indispensable to every one whose duties or inclination induce him to investigate any of the phenomena connected with the organic or inorganic world, or that a correct acquaintance with even the rudiments of chemistry cannot be obtained without them; the effects of chemical affinity and electric action being so connected, that, in the opinion of one of the most eminent philosophers and successful cultivators of science of the present day, they depend upon one and the same cause for their production and effects.

Complex and obscure as the laws of the materal universe may appear to the superficial observer, surrounded by difficulties and lost in the maze of phenomena around him, he might be tempted, like the philosophers of old, to refer every

* φύσις natura.

effect to its own peculiar cause; a cause innate to the substance, essential to it, and animating like a soul. Far otherwise are the conclusions arrived at by him who, patiently investigating the appearances of the material world, is guided by the inductive reasoning of the Baconian school: *he* traces effects to their proximate causes, and generalizing these, is led to the discovery of a few simple laws, obeying which, atom unites to atom, and mass to mass, to form a world, and roll in its appointed sphere around the centre of our system, the great source of light and heat;—*he* soon discovers that, in the beautiful simplicity of Nature's laws, the apparently most insignificant, and the most gigantic effects are frequently produced by one and the same cause; *he* discovers that the very law which presides over the motions of the luminous orbs which roll in space around him, causes the scattering of flour from the edge of the millstones, and of drops of water from the wet revolving carriage wheel. That the law regulating the falling of an apple towards the earth, is identical with that which retains the mountains on their broad bases and the planets in their spheres.

Experience and observation constitute the true guides for the investigations of the philosopher; and aided by the soundest inductive reasoning they, in the hands of the immortal author of the Principia, developed those great truths which astonished the world, and whose light ultimately dispelled the last traces of obscurity with which the Aristotelian and Cartesian systems continued to encumber philosophy. The celebrated *Reguli Philosophandi* left us by Newton cannot be too deeply impressed upon the mind of the student, and should be confided in as his best guides in reasoning from experiment.

RULE I.

We are to admit no more causes of natural things than such as are both true and sufficient to explain their appearances.

RULE II.

Therefore, to the same natural effects we must, as far as possible, assign the same causes.

RULE III.

The qualities of bodies, which admit neither intension nor remission of degrees, and which are found to belong to all bodies within the reach of our experiments, are to be esteemed the universal qualities of all bodies whatsoever.

RULE IV.

In experimental philosophy, we are to look upon propositions collected by general induction from phenomena as accurately, or very nearly true, notwithstanding any contrary hypothesis that may be imagined, till such time as other phenomena occur, by which they may either be made more accurate, or liable to exceptions.*

Before we can satisfactorily proceed to an investigation of the laws governing matter, in the masses in which it is presented to our senses, it is obvious that something approaching to a succinct and tolerably clear view of the internal composition of each individual material mass should be obtained. By the physical composition of a mass of a material substance, we by no means refer to its physical composition; we do not enquire which or how many of those substances, which chemists at present consider as primary or simple, are present; we refer solely to the physical constitution of the mass. Thus, for example, in a ball of marble, which is known to consist of carbon, oxygen, and calcium, it is not enquired how much of these respective ingredients are present, but *in what manner* the minutest physical atom of the compound (chemically speaking) substance, marble, is held in connexion or relation to that next to it.

It would be useless to occupy time by recapitulating all

* Princip. Math. Philos., lib. iii.

the theories that have been proposed for the resolution of this question from the time of Leucippus, Democritus, and the great philosopher of Stagyra, to that of our own era. Beautiful and ingenious as many of these hypotheses are, they often fail to bear the rigid investigation of truth, and too frequently are found to have their superstructure based on no better foundation than the brilliant and fertile imaginations of those, who introduced them to the world.

If we take a mass of any form of matter and reduce it to the finest impalpable powder by any mechanical means, it must not be considered that this state of comminution, however fine and minute, has put us in possession of atoms of matter in their minutest state of division; for, on examining with a lens a particle of the powder thus obtained, we find it to closely resemble the mass from which we obtained it, and of which it is in every respect a miniature likeness. So that it is probable that had we cutting instruments sufficiently delicate, and visual organs sufficiently microscopic, we might continue dividing this particle into numerous smaller portions. This circumstance has been very lately proved, by the microscopic labours of Ehrenberg, to be strictly and literally correct, and to hold good where it was least expected. This philosopher, among other observations, has shown, that chalk in its minutest state of comminution, after it has been exposed to the action of a mill, and then the finest portions separated by the operation of elutriation, still under a good microscope appears to be composed of transparent rhomboids, with angles as perfect as in the finest specimen of calcareous spar. Here arises the first question in this stage of our enquiry; for, admitting that we are able to continue our division of the particles, we should naturally ask, what would be the limit to this division?—could it be carried on to infinity, or is there a point at which it must stop? Some philosophers, there are, who consider that this state of division may be carried on to infinity, and, consequently, that matter is divisible for ever. If this be the case, there can be no such thing as an atom; certainly not, if its strict definition be adhered to. What then can a mass of matter be constructed of? Can it be supposed to consist of an aggregation of infinitely divisible particles? If so, of what are these particles themselves composed, if their division can be continued for ever? So that we are almost compelled to regard the division of matter as limited; for, if we do not admit this finite division of masses, we can have no idea, or capability of appreciating its compound particles. To appreciate numbers, we must be acquainted with the number of units they contain; to appreciate a mass, we must admit the existence of a finite division into particles or atoms. Again, matter no one can suppose to be else than mortal; it is no attribute of spiritual or immortal beings; then, if we admit that matter is essentially connected with beings which are limited in duration of existence, does it not appear to involve an absurdity to suppose that the constituents of that which is limited in existence are infinite in number? "It would be as easy to believe that a moment of time may be lengthened into an infinity of ages, as to suppose that matter is infinitely divisible. Nothing can be more revolting to reason than eternal time; infinite divisibility is not less absurd;" although it must be acknowledged a most difficult task to adduce a precise refutation of all the mathematical sophistry and subtleties concerning infinite divisibility, with which the question has been loaded. The mind is unable to continue the contemplation of this subject; it becomes bewildered in the mazes of the question, and seeks for relief from the obscurity enveloping the labyrinths, which the thinking powers are unable to penetrate, in the consideration of those deductions countenanced by reasoning, experiment, and experience.

We have next to enquire, by what force the particles of matter, which we have obtained from the mechanical comminution of a mass, were held together previous to their forcible separation. Some force must exist for this purpose, otherwise no such thing as an aggregation of atoms forming a mass could ensue; for we can consider particles of dead matter only as absolutely inert, and, therefore, of themselves could not oppose that obstacle to their forcible separation which is presented by every solid material mass; and this reasoning brings us to notice a most energetic force presiding over the internal constitution of bodies. This force is *attraction;* and by its aid one particle of matter is held in close approximation to a second, and thus causes the formation of a mass. Reasoning from known facts, teaches us that this attractive force must be considerable, otherwise it would be impossible to account for the difficulty we experience in attempting to divide a mass of any substance; it also teaches us that the sphere of this attraction is limited to distances quite insensible to the eye, even when assisted by the best microscopes. For, having once reduced a mass to powder, the minute particles composing this, ought again to unite on collecting them into a heap on a piece of paper; for the particles appear to the naked eye to touch each other, and therefore to afford every opportunity for the exertion of a mutual attractive force to reconstruct the mass we have disintegrated. But we know that this attraction does not become apparent; the particles of matter do not fly together, unite, and form a mass; therefore, it must follow that the sphere or extent of this attractive force is extremely limited.

The attraction between two particles cannot be *infinite,* for, if so, no earthly power could effect their separation; hence there must exist some power or force modifying this attraction, acting consequently in opposition to it. For it appears evident from the results of experiment that, although two particles have so powerful an attraction for one another, as soon as they are brought within the sphere of each other's attraction, that they unite and constitute one mass; yet, that if it be attempted to bring them into absolute contact, a most powerful resistance is opposed to our attempts, and the task becomes impossible, demonstrating the existence of a repulsive force between individual particles as well as between masses of matter. Admitting the existence of these two forces, attraction and repulsion, acting on the particles of matter, let us investigate the attributes of the latter in its minutest physical state of division, rejecting entirely the hypotheses I have hinted at, which consider matter either as infinitely divisible or as entirely non-existed; for theories of this kind must be regarded as purely metaphysical, and, therefore, quite distinct from our present investigations. Indeed, by reasoning on matter in the abstract, we gain comparatively little; it is by studying it in relation to other masses, and the external world, that we gain anything practically useful.

It has been fairly deduced from accurate reasoning and observation, that all ultimate physical, indivisible atoms, possess the attributes of impenetrability, hardness, and figure. What their form really is, it is impossible to say: philosophers have exhausted the fertility of their imaginations on this subject; the ancients supposed them to be possessed of various forms; most modern writers have assumed them to be spherical; and, certainly, in reasoning on their properties and attributes, this form is found most available; a late Italian author has attempted to prove them to be pyramidal. To enter into these speculations would however be useless and unprofitable, as it is self-evident that no direct proof can be brought to bear upon the subject. If the component atoms of any form of matter be placed sufficiently near to each other, by the action of a mutually attractive force, we have a *solid* produced; if a repulsive energy be now exerted, the atoms fly asunder, and we have a *soft solid*, or *liquid;* and this, upon a still further application of repulsion, becomes converted into a *gas*, or *vapour*, from the more distant separation of its component atoms. As an example of these different states, let us take ice. This is a well known solid of considerable hardness, justifying the idea that its atoms are very closely approximated to each other; on applying a gentle heat, these atoms separate and a fluid, water, is produced; a still greater degree of heat causes a further separation of atoms, and a vapour, steam, is generated: in this state a given number of atoms occupy a space 1728 times greater than they did when constituting fluid water. Many other forms of matter may be made to assume the several states of *solid*, *fluid*, and *gas*. In the case of carbonic acid this is beautifully demonstrated, an invisible gas having, under powerful pressure, its molecules so approximated that a fluid is formed; and then, under the influence of intense cold, a still further approximation ensues, and a white solid, resembling snow, is produced. All these several states of matter will fall under our observation in the investigation of the sciences of Statics, Dynamics, Hydrostatics, and Pneumatics. (Chap. I—VIII.)

Masses of matter constituted in the manner thus described are said to be *brittle*, if the attraction between their atoms are so slight as to be overcome by a slight blow;—to be *tenacious*, if this attraction is so intense that it cannot be readily overcome;—and to be *elastic*, if upon the application of force, their atoms allow of partial separation, and rapidly reunite on the removal of pressure. If, for example, a glass vessel be lightly struck, its atoms momentarily separate, then rapidly return to their normal state, by a series of isochronous oscillations, their movements are communicated to the air, an eminently elastic body; alternate dilations and contractions ensue in those layers of air nearest the agitated body, these become gradually extended into the great mass of atmosphere, like the waves formed on the surface of a lake by the falling in of drops of rain, and gradually extend in rapidly dilating circles until they vanish from the eye of the observer. When these vibratory movements occur with sufficient rapidity, they excite in the organs of hearing that sensation termed a *sound*, and on the quickness or slowness of their succession depend all the varieties of grave and shrill tones. Less than sixteen vibrations in the second are imperceptible as a continuous sound to the most delicate ear, whilst the greatest number perceptible in that time are less than twenty thousand, producing an exceedingly sharp sound, or rather shriek. An examination of these effects belongs to the science of *Acoustics.* (Chap. IX.)

Having assumed that all matter is made up of material, minute, indestructible, spherical atoms, we see at a glance that, let the attracting force emanating from their centres be ever so intense, interspaces *must* exist. Now, as to the state of these interspaces, more discrepancy of opinion has existed than on any other point of philosophic enquiry ; some supposing them to be empty, others filled with an ethereal matter. Here Descartes found his vortices ; and here the more ancient philosophers located their ether, animating the mass, and enduing it with its peculiar properties. The latter opinion, although exploded for ages, is probably, with some modification, very near the truth; all reasoning and all experiment tending to the belief that these interspaces are filled up by an imponderable form of matter, playing a most important part in the phenomena of the material world. Such, indeed, appears to have been the opinion of Sir Isaac Newton, who refers, in the queries appended to his Optics,* to some of the probable properties and effects of this subtle and imponderable form of matter. His almost superhuman mind even grappled with the difficult question of the probable density and elasticity of this medium, as compared to air. Although possessing but slender data for investigation, derived chiefly from the rapidity of propagation of sound, as compared with that of light deduced from the horizontal parallax of the sun, Newton has shown that imponderable ether must be at least 700,000 times less dense than air; and that its elastic force, as compared to its density, must be, at the lowest estimate, 490,000,000,000 times greater than that of air. It is obvious that this imponderable form

* Optice, sive de reflexionibus, &c., lucis, lib. iii., Qu. 18 24. London, 1719.

of matter, or ether, which we have assumed as occupying the interspaces existing between the solid particles of ponderable matter, is not limited to these localities, but independent of occupying what would otherwise be vacua between the gaseous atoms of our atmosphere, even in its most attenuated state, extends beyond its confines, and beyond those of all the ponderable elements of our globe, into space; forming an invisible and imponderable fluid ocean, in which the vast orbs of our universe roll unimpeded in their majestic courses.

It has been objected to this view of the presence of imponderable matter beyond the limits of our own world, that it has no further foundation for its existence than the necessity of its presence to support the undulatory hypotheses of light and heat. And it has been stated, that, were space actually full of this matter, we should expect a certain amount of retardation in the velocity of the planets of our universe. But when the extreme tenuity of ether is considered, no considerable amount of influence on the movements of the heavenly bodies can reasonably be expected; still, from some minute observations of Encke,* on the motion of the comet which bears his name, it appears that the resistance of the imponderable and ethereal medium in which it moves has not been without its influence; and that a certain, and not very inconsiderable amount of alteration in the velocity of this wandering mass has really taken place. A fact, weakening the force of one of the most plausible experiments against the hypothesis of the existence of ether in space.

There is this remarkable apparent difference between ponderable and imponderable matter, that, whilst to cause the former to assume motion, absolute contact with another ponderable mass is required, the latter assumes that state without visible contact, and even at considerable distances from the moving power. This may, however, be after all

* Bode's Astronomisch. Jahrbuch, 1823. p. 216.

only an apparent difference, absolute contact of ethereal atoms through the medium of the atmosphere in all probability occurring, although not obvious to us on account of the invisible nature of the agent whose effects we are examining. Thus, a bar of iron, whose imponderable interstitial atoms have been, by a process elsewhere described, arranged in such a manner as to present the phenomena of magnetism (Chap. X.) may be placed upon a pivot, and yet assume no motion without contact of the hand; on approaching it, however, by a second mass of iron, whose ethereal atoms have been similarly arranged, the suspended bar moves long before contact of the two bars occurs. This imponderable ethereal matter may be occasionally elicited in a state accompanied by luminous phenomena, as on turning the plate of an electric machine vivid flashes of light rush to the hand held near the apparatus; presenting us with mimic lightning of the same nature, and similating in its effects that which terrifies us when exhibited on the large scale in the theatre of nature. These effects we shall study when investigating the science of electricity. (Chap. XI—XIX.) One of the most remarkable properties of this form of imponderable matter is the power it possesses of rushing through dense metallic wires like water through open tubes; this, and its invisibility, caused it to be ranked among the most mysterious agents; and its almost miraculous effects would, had they been known in the middle ages, have placed, as a knowledge of magnetism in one instance really did, its cultivators in danger of the stake at the hands of inquisitorial ignorance, for a supposed connivance with the powers of darkness.

The subtle and invisible forms of ethereal matter, when caused to assume a vibratory or undulatory movement with sufficient rapidity, produces a peculiar set of phenomena, whose effects are known by the terms of light and heat; effects of vast importance, for without them nature would be dead to us, its beauties no longer apparent, and this world a cheerless waste. The vibrations of ethereal matter required for the production of the perception of colours are inconceivably rapid, no less than 458 millions of millions in a second of time, being required to communicate to the retina the sensation of scarlet, and 727 millions of millions in the same space of time to communicate that of violet; and to appreciate these rapid undulations has the delicate mechanism of the eye been arranged by an All-wise Creator. The consideration of these phenomena is the province of the science of Optics. (Chap. XX—XXV.)

In the foregoing observations I have thus given a view of the constitution of masses of matter, sufficiently extended to enable the student to commence an investigation of their properties, and have pointed out to him those beautiful and important branches of science, to the elementary investigation of which, these pages are devoted.

To this no less interesting, than important and attractive series of investigations, the attention of the student is now invited, confident that all the difficulties that may at first appear in his course, will disappear by a very little exertion of patience and attention, and that, instead of proving stumbling-blocks, they will furnish so many stimuli to exertion. And that he will ultimately reap a rich reward for his labour, by finding his knowledge of Nature's works and laws improved, and to a certain extent, let us trust, perfected; whilst the professional student will, in his own peculiar department, find his knowledge of the action of the heart and circulating system improved by an acquaintance with the laws of fluid motion; that his knowledge of the physiology of the respiratory functions, will not be diminished by an acquaintance with the laws of atmospheric pressure; that his ideas of the physiology of muscular action will be extended, by being able to explain it on mechanical principles; and that his knowledge of many vital functions will be increased and furthered by the study of electric currents.

These are but a few of the attractions which a study of physics hold out. I might also refer to the connection of the physical sciences with the ordinary duties of life, and allude to their infinite importance in affording the key to a vast series of natural phenomena, as well as to the sources of gratification experienced from an acquaintance with the laws governing the hurricane, the torrent, and the tempest; by which these otherwise terrific agents become divested of half their terrors, by our being able to remove those with which popular superstition and ignorance have surrounded them.

These are some of the rewards extended to those, who pay even a slight attention to the physical sciences. They are raised above their fellow men by their increase of knowledge, knowledge of the most valuable kind, applicable in a greater or less degree to their different professions, and to all the resources of civilized life; whilst, from gazing on His beauteous works, and admiring the harmony and simplicity of the laws He has impressed on nature, they are compelled to regard with no less gratitude than admiration their divine author, and become enabled to appreciate the full force of the sublime and beautiful remark of one of the most celebrated philosophers* of ancient Greece, who, more than twenty-two centuries ago, notwithstanding his necessarily very limited acquaintance with the laws governing the universe, declared that—

"The world is God's epistle to mankind."

We are also taught how we may more "nearly behold the beauties of nature, and entertain ourselves with their delightful contemplation; and, which is the best and most valuable part of philosophy, be thence excited the more profoundly to reverence and adore the great Maker and Lord of all. He must be blind who, from the most wise and beautiful contrivances of things, cannot see the infinite wisdom and goodness of their Almighty Creator; and he must be mad or senseless who refuses to acknowledge them."†

* Plato. † Cotes's Preface to the Second Edition of the Principia, 1713.

SECTION I.

PHYSICS OF PONDERABLE MATTER.

Elementary Laws and general Statics, Chapter I—II. General Dynamics, Chapter III—IV. Simple Machines, Chapter V. Physics of Liquids at rest, or Hydrostatics, Chapter VI. Physics of Aerial Fluids at rest, or Pneumostatics, Chapter VII. General Properties and Laws of Fluids in motion, or Hydro- and Pneumo-dynamics, Chapter VIII. Sonorous vibrations of Ponderable Bodies, or Acoustics, Chapter IX.

ELEMENTS

OF

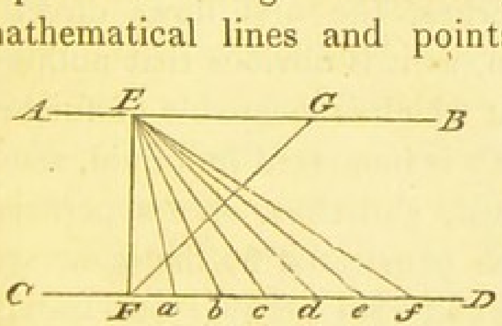
NATURAL PHILOSOPHY.

CHAPTER I.

GENERAL PROPERTIES OF MATTER IN ATOMS AND MASSES. (STATICS.)

Finite Divisibility of Matter, 1. *Essential Properties of Atoms—Impenetrability, Extension, and Figure*, 2-3. *Molecular Forces*, 4. *Accessory Properties of Matter—Divisibility, Flexibility, Tenacity, Brittleness, Elasticity*, 5-9. *Inertia*, 10.

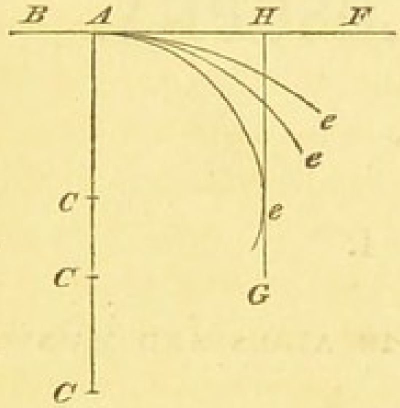
1. ALL varieties and forms of matter are similarly composed, being made up of an immense number of extremely and almost inconceivably minute, indestructible particles, which, from their not admitting of further mechanical division, are termed *atoms.** Some philosophers have, however, conceived that no true atom exists, and that all matter is capable of undergoing division to infinity, a statement capable of being satisfactorily applied, when limited to mathematical lines and points. Thus, let ABCD be lines drawn parallel to each other, and connected by the perpendicular EF: draw the oblique line FG, and from F on the indefinite right line CD take any number of



* A, and τεμνῶ, scindo.

equal parts, as F*abcd*, &c. From E draw lines connecting this point to *abcde*, &c., cutting the oblique line FG; then, as the number of points *abc*, &c., on the line CD may be infinite, it follows that the line FG may be infinitely divided by lines connecting such points to E.

Another mode of proving the same statement is by drawing two right lines ACGH perpendicular to BF, from the points CCC, as centres, describe, with the distances CA as radii, the circular arcs A*e*, A*e*, &c. Now the greater the radius AC, the smaller must be the part cut off from the line HG, and as the radius may be increased to infinity, the part *e*H may be diminished in a similar ratio, never becoming reduced to nothing, as the circular arc described with the longest radius can never entirely coincide with the right line BF, consequently the parts of any magnitude GH may be diminished to infinity.



Arguments of this kind ought rather to be regarded as applicable only to mathematical lines and points, which, the former being without breadth and the latter without length,* can be regarded but as mental conceptions, and not physical existences.

2. The ultimate particles or atoms (1) of matter possess the three *essential* characters of impenetrability, extension, and figure. Of these properties, the first flows directly from the definition of an atom, as it is obvious that nothing can be so impenetrable as that which is incapable of further division. When any solid body is immersed in a fluid, some portion of the latter is displaced, and thus, on a superficial view, might be supposed to be penetrated by the immersed body; it will, however, be found that no real penetration occurs, as a quantity of fluid becomes displaced, equal in

* Euclid, Book I., defs. 1, 2.

bulk to the solid immersed (132). Again, on forcing a nail or a knife into a piece of wood, the ultimate physical atoms of the latter are not penetrated, the instrument being merely insinuated into the interstices existing between the indivisible molecules. Upon this character of impenetrability depends the great physical axiom, that no two bodies can occupy the same space at the same instant of time.

The second character, or extension, is also a necessary consequence of the definition of an atom already given, as that which possesses a physical existence must necessarily occupy a portion of space, and possess sides and surfaces in relation to other atoms.

The third character, figure or form, is also essential to the existence of an atom, as nothing can be conceived as physically existing, unless it possesses some determinate shape, although this property is not sufficient of itself to prove the material existence of an object; for in shadows and spectral illusions, produced by various optical means, we have examples of figure or form without matter.

Of the actual form or dimension of atoms nothing positive is known; it is, however, probable that they are spherical, but of their dimensions scarcely an approximation can be obtained by any means we are yet acquainted with. An ounce of gold can be drawn into wire several miles in length (5), and yet no flaw, or evidence of separation between its atoms can be discovered by the closest microscopic examination. Animalcules also exist, so minute that myriads can swim in a drop of water, and yet each individual possesses organs of digestion, circulation, and reproduction, made up necessarily of an immense number of atoms. Chemistry affords us evidence of the excessive minuteness of atoms, for when several metals, as nickel, cobalt, or iron, are reduced from their oxydes at the lowest possible temperature by means of a current of hydrogen gas, the state of division of the reduced metal is almost inconceivable. Each particle of metal evolving its oxygen forms a portion of a powder which may be considered as composed of ultimate atoms. These are in every case less than $\frac{1}{10,000,000}$ of an inch in diameter, so that by a simple calculation it may be proved that a cubic inch of them would, if extended on a level surface so that they may touch but not overlap each other, cover an area of 218,166 square feet, or more than five acres of ground.*

3. The minute atoms composing *masses* of matter may be, and often are, chemically compound, although physically simple; thus a piece of marble may be divided into its ultimate molecules, each consisting of carbonate of lime, and here physical analysis stops; but by chemical analysis we can separate each of these atoms into carbonic acid and lime, the former being again chemically divisible into carbon and oxygen, and the latter into calcium and oxygen. In physics, therefore, an atom is regarded as simple when it cannot be further divided without separating its chemical elements.

4. Atoms are held together by means of a force denominated *attraction*, the firmness of their union being modified by the presence of an opposing force, termed *repulsion*, and upon the preponderance of one of these forces over the other depend all the physical properties of matter, known as *hardness*, *softness*, *fluidity*, &c. Attraction and repulsion are mutually exerted from the centres of each atom with an intensity, decreasing with the squares of their distance (12). If the mutual attraction of atoms be so considerable as to prevent a sharp body, as a knife, being inserted between them, the mass is said to be hard; but if so feeble as to permit their ready separation, the resulting mass is soft; and a fluid or gaseous body results when the intensity of the mutual attraction between the atoms is so far diminished, as to allow any substance to be moved between them without experiencing any considerable resistance.

* Mitscherlich, Lehrbuch der Chemie, p. 384.

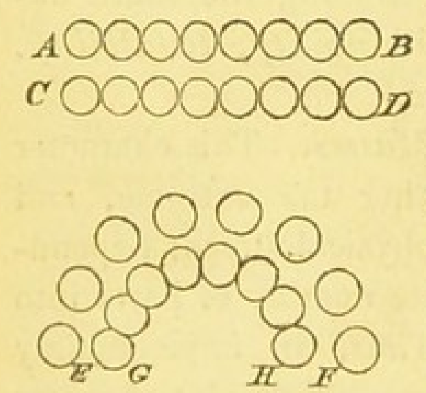
Thus the various states in which matter exists, as *solid, viscous, liquid, or gaseous*, merely depend upon the varying intensity of the molecular forces of attraction and repulsion. These several states are readily convertible into each other by various mechanical means, and by alterations of temperature; thus, water at 32° and mercury at 72° lower, are solids, the one being transparent, the other opaque (424). At ordinary temperatures both are liquids, whilst at 212° water, and at 670° mercury, become vapours or gases, both being transparent; these several changes depending merely on the greater separation of their atoms by the addition of caloric. The density of matter in any of its three states is measured by the quantity contained in a given bulk, and is expressed by its specific gravity or specific weight, as compared with some body taken as a standard; thus, if a given bulk of water contain 1000 atoms of matter, a similar bulk of platinum will contain about 23,000; of copper nearly 9000, of iron 8000, and of glass about 3000: these several numbers being identical with the specific weight or gravity of the respective substances.

Masses of matter moreover possess several properties which may be considered as accessary, all depending upon the different degrees of intensity with which the physical atoms are mutually tied together. Among the more important of these may be ranked, *Divisibility, Flexibility, Tenacity, Brittleness, Elasticity*, &c.

5. *Divisibility* or *Extension of Masses.* This character may be considered as well illustrating the extreme, and almost inconceivable minuteness of physical atoms; depending upon the immense, although finite number of parts into which a mass may be divided. Thus, an imperceptibly small portion of strychnia will render a whole pint of water bitter, and a single grain of the ammoniacal hyposulphite of silver will render intensely sweet 32,000 grains of water; one grain of iodide of potassium dissolved in 480,000 of water, when mixed with a little starch, will tint every drop of

the fluid blue on the addition of a solution of chlorine. In all these cases, we have at once evidence of the extreme minuteness of atoms furnished by the divisibility of the masses or aggregation of atoms by means of solution. When animal or vegetable substances are burnt, they are neither consumed nor destroyed, their atoms are merely divided or separated from each other to form new combinations. Excellent illustrations of the same property are met with in many processes of art; a single pound of wool will furnish a piece of yarn 100 miles in length. Gold under the hammer is reduced to such a state of tenuity, that 360,000 of the leaves produced would, if piled on each other, only equal the thickness of an inch. Even this is far exceeded in the art of the wire-drawer, who, in the most economical mode of preparing gilded silver wire, extends two ounces of gold over a length of 1,351,900 feet, or rather more than 768 miles.

6. *Flexibility.* When any substance is capable of being bent in any given manner within moderate limits, by the application of sufficient force, it is said to be *flexible;* for a body to possess this property it is necessary that the attraction existing between one portion of its atoms should be capable of being partially overcome, and that between another portion proportionably increased: thus, if ABCD represent two rows of atoms situated at their normal distance from each other, on applying force sufficient to flex the whole into the curved form EFGH, the arc EF will be larger than the arc GH, and, consequently its atoms will occupy a larger and those of the lesser arc a smaller space than they did when in the rectilineal figure. Lead, gold, annealed copper, soft iron, wax, &c., are examples of flexible bodies.



7. *Tenacity.* This character is dependent upon the

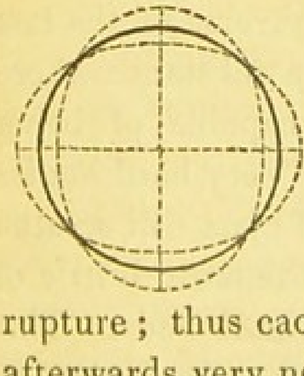
intensity of attractive force existing between atoms being sufficient to oppose their separation, to such an extent as to cause the rupture, or fracture of the whole mass, consequently, all flexible, ductile, and malleable bodies are tenacious; although many substances possess the latter property without any of the former. Tenacity varies extremely in different substances: metals afford the best examples of it; thus, a piece of steel wire of given diameter is capable of supporting without fracture 39,000 feet, or seven miles and a half of its own length. Wire of different metals of the same diameter, require different weights to overcome the mutual attraction of their component atoms, as shown in the following table, the figures representing the number of pounds weight required to break wires ~~one~~ 0.1 inch in diameter of the metals enumerated.

Metals.	Pounds required to produce fracture.
Bismuth	20·1
Lead	27·7
Tin	34·7
Zinc	109·8
Gold	150·07
Silver	187·13
Platina	274·31
Copper	302·26
Iron	549·25

8. *Brittleness.* This is obviously the converse of the last character; it points out that condition of a substance where the attraction between its molecules is capable of being overcome by a comparatively slight force. Very hard bodies are often extremely brittle; thus, a piece of glass will scratch the surface of polished steel, and yet is the most brittle of substances, unless spun into exceedingly fine threads. This property is frequently acquired during the *hardening* of bodies, when their atoms are brought nearer each other's

repulsive influence; thus soft steel is tenacious, yet a hard knife-edge is as brittle as glass, cast-iron is extremely brittle, and bar-iron is the toughest substance in nature.

9. *Elasticity*. A body is said to be elastic when, after being bent in any direction, it spontaneously recovers its former shape on the force which had altered its figure being removed; all elastic bodies must be so constituted as to allow a certain number of their atoms to be brought, at least momentarily, nearer each other than they previously were. If the body be a metallic rod, then, on being bent (see last figure) in the curved form EGHF, it will have a tendency to assume its primitive rectilinear form on the removal of the coercing force, in consequence of the exertion of two forces, viz. attraction between the partially-separated atoms on the outside, and repulsion between the unnaturally approximated atoms on the inside of the curve; the rod will obey these forces, and after a few oscillatory or vibratory movements will, if perfectly elastic, recover its primitive form. In this case, the change of form which brought into action the elasticity of the body is very obvious, from the curve produced by its flexure; sometimes this change of figure, even in the most perfectly elastic bodies, is not evident to the eye, on account of their figure; still such change does demonstrably take place. Thus a ball of ivory is elastic, and this property causes it to rebound from the floor when forcibly thrown upon it, its figure, on its impact, becoming altered and compressed, nor does it again become spherical until after it has



for some instants been an ellipsoid, of which the greater diameter is successively horizontal and vertical, as shown by the dotted curves in the marginal figure. Different elastic bodies vary extremely in the extent to which they will yield without rupture; thus caoutchouc will yield considerably, and will afterwards very nearly regain its former shape, unless it has been stretched for some time. Glass threads, steel springs, unannealed copper and brass, are all elastic. Among the most elastic bodies are gases: these, on account indeed of their physical constitution (4), will permit, on the application of sufficient force, their atoms to be very closely approximated, again separating with rapidity, and even violence, on the removal of pressure; the air-gun and condensed air-fountain are examples of this property in atmospheric air.

10. All forms of matter, whether in the atom or in the mass, are alike inert, and incapable, by the exertion of any spontaneous force, of changing their state or position: *wherever* a body is placed by any external causes, there it must remain for ever, unless acted upon by some superior force. This property of matter is termed its *Inertia,* or resistance to a change of position; this is not merely a passive sluggishness, but an actual resisting force, which increases in the direct ratio of the increase of weight of the body. The resistance experienced in first setting any body in motion, and the difficulty experienced in stopping it when moving, arise equally from this cause; for being absolutely inert, it follows that matter must retain its state of motion, as well as of rest for ever, unless acted on by opposing forces. The following are examples of the force of inertia: in turning a winch a decided *resistance* is at first experienced to our attempts, this becomes gradually overcome, and then the wheel continues to move rapidly by the continued application of a slight force, just sufficient to overcome the resistance offered by the medium in which it moves, and the friction at the points of suspension. In a team of horses attempting to move a heavily laden wagon, an immense exertion of muscular force is required to overcome its *inertia,* but this once effected, the horses continue to draw that weight with facility which at first they were scarcely able, by the utmost exertion of their physical force, to move. A traveller sitting in a coach, on the horses starting, is thrown backwards; his *inertia* opposing a resistance to his body acquiring at once the move-

ment of the vehicle, and therefore tends to leave him behind; and on the coach stopping, he is thrown violently onwards, from his corporeal *inertia* tending to retain the motion previously acquired. A bullet thrown at a pane of glass breaks it into thousands of pieces; but fired from a rifle at it, it merely pierces a circular hole, from the *inertia* of the glass rendering it impossible for every portion of the latter to acquire suddenly the rapid motion of the bullet, and consequently that portion only opposed to the point of impact is carried onwards, and participates in the rapid motion of the ball.

CHAPTER II.

NATURE OF THE ATTRACTIVE FORCES EXERTED BETWEEN MASSES OF MATTER. (GENERAL STATICS AND DYNAMICS.)

General Law of Attraction, 12. *Cohesion*, 12-15. *Capillarity*, 16-23. *Endosmose*, 34. *Gravitation*, 25-30. *Centre of Gravity*, 31-36. *Equilibrium*, 37.

11. ATTRACTIVE forces, capable of acting not only between atoms but also between masses, exist; and form a very important subject of consideration. Molecular attraction of aggregation, which ties atom to atom has been already alluded to. We have next to examine those forces which act between masses of matter: these may be divided into two sections, the first comprehending attractions at insensible distances, including cohesion and capillarity; the second, attractions at sensible, and often at immense distances including gravitation.

12. All attractive forces diminish in intensity as we recede from the centres of the attracting molecules or masses, and obey one general law of *the attractive force being inversely as the squares of the distances between the attracting bodies.* Attraction is always mutual and exerted by one body on another, *cæteris paribus,* in the ratio of their masses. As an example of the general law of attraction, let us suppose that two bodies, A and B, mutually attract each other when at a certain distance with a force equal to 1, at double that distance, this force will be $\frac{1}{4}$ instead of $\frac{1}{2}$ of that when at a

distance of 1, because the square of 2 is 4; at four times the distance, the force will be diminished to $\frac{1}{16}$, and so on. In the following table the upper line contains a series of figures representing the mutual distances of the attracting bodies, and the lower line a series of fractions representing the intensity of attractive force at those distances.

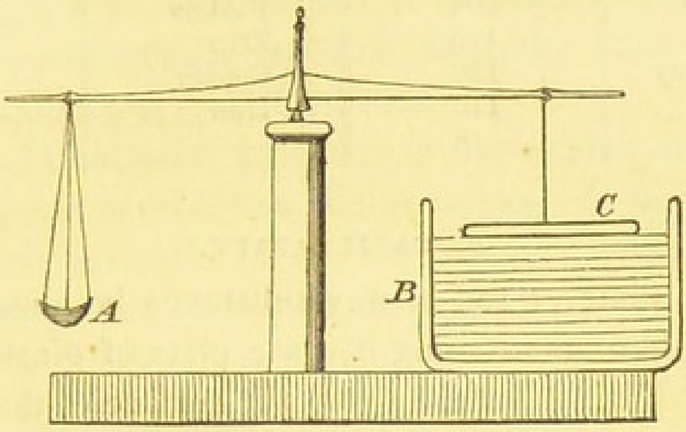
Distance	1	2	3	4	5	6	7	8	9	10	11	12	13	&c.
Intensity of Attraction	1	$\frac{1}{4}$	$\frac{1}{9}$	$\frac{1}{16}$	$\frac{1}{25}$	$\frac{1}{36}$	$\frac{1}{49}$	$\frac{1}{64}$	$\frac{1}{81}$	$\frac{1}{100}$	$\frac{1}{121}$	$\frac{1}{144}$	$\frac{1}{169}$	&c.

Attraction at insensible distances.

A. COHESION AND ADHESION.

13. Whenever two smooth surfaces are pressed together, a considerable resistance is experienced in attempting to separate them: this is owing to an attractive force called *cohesion*, so termed from its causing their surfaces to cohere or stick together. To observe the effects of this force advantageously, the surfaces of the bodies pressed together should be absolutely smooth; but as this is impossible, they should be polished and then smeared with a little oil to fill up any superficial inequalities: two plates of brass or glass thus prepared, and firmly pressed together with a screw-like motion, will cohere with such force as to require a considerable weight to separate them. Two freshly-cut surfaces of caoutchouc will, on being pressed together, cohere so tightly that it is scarcely possible to separate them; and availing himself of this fact, the chemist prepares tubes of this valuable substance, applicable to numerous important purposes in his manipulations.

14. Cohesion takes place not only between the surfaces of solids when sufficiently approximated, but between solids and liquids: this variety of attractive force has been termed adhesion.



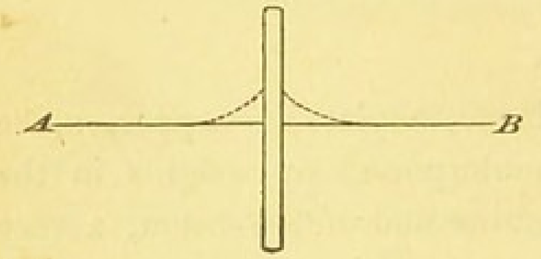
If from one arm of a balance, a plate of copper, C, be suspended, and carefully counterpoised by weights in the scale suspended from the opposite end of the beam, a very slight additional weight will cause either the plate or the scale to preponderate; place a basin full of water, B, under the plate, C, in such a manner that the latter may just touch the surface of the water in B; on placing weights in A, a very considerable resistance is experienced to the separation of C from the fluid surface, owing to this cohesive attraction. With a circular plate of smooth copper, presenting an area of 6·75 inches, the weights required to overcome the attraction of the metallic surface for the water exceeded 1000 grains.

15. The intensity of this force, although constant, *cæteris paribus*, for the same solids and liquids, varies considerably in different kinds of solids or liquids; the following table represents the comparative intensity of the cohesive attraction exercised between different metallic surfaces and mercury:

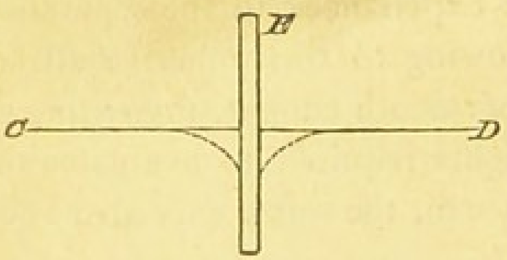
Metal Disks, 1 inch in diameter.	Force of cohesion* in grains.	Disk of Metal.	Comparative force† of Cohesion
Gold	446	Gold	23·63
Silver	429	Silver	22·74
Tin	418	Tin	22·15
Lead	317	Lead	21·04
Bismuth	372	Bismuth	19·71
Zinc	204	Platina	14·98
Copper	140	Zinc	10·81
Antimony	126	Copper	7·52
Iron	115	Iron	6·10
Cobalt	8		

B. CAPILLARITY.

16. If a plate or rod of any substance be plunged into a fluid capable of moistening it, as a plate of glass in water; the surface of the fluid, AB, instead of remaining perfectly horizontal, will rise to a higher level at the sides of the plate, as shown by the dotted lines, as if the water were attracted by the glass.



If the glass plate be slightly greased prior to immersion, or be plunged into a fluid incapable of moistening it, as mercury, then a depression instead of elevation will take place on either side of the plate. If a plate of glass, E, be plunged into mercury, CD, this apparent repulsion will take place; this appears to be owing less to any peculiar property of fluid metal than to the presence of a minute film of moisture adhering to the immersed solid.

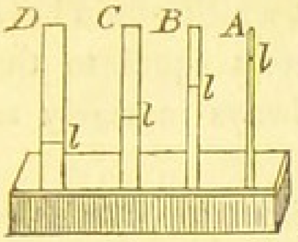


17. These phenomena are best witnessed by immersing glass tubes of small diameter in water tinted with archill or

* Guyton Morveau, in Kastner's Experimentalphysik. Heidelberg, 1810.

† Quetelet, Positions de Physique. p. 104. Bruxelles, 1834.

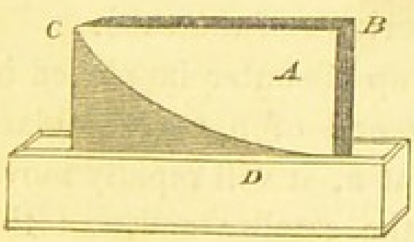
ink; the fluid will rapidly rise above the exterior level in the tubes, attaining the greatest elevation in the finer or capillary tubes; thus it will rise much higher in A than in B, in B than in C. &c.: this mode of attraction, evidently a modification of the last described phenomena, is termed *capillarity* from its being most obvious in tubes of capillary or hair-like bores.



The height attained by fluids in these tubes is constant and increases inversely as the diameters of the tubes; it bears no evident ratio to the density or specific gravity of the fluid employed in the experiment; for Muschenbröck* found that in tubes of equal diameter fluids rose to the comparative heights shown in the following table:

NAME OF FLUID.	ELEVATION.
Sulphuric acid	1·30
Sulphuric ether, containing alcohol .	1·40
Anhydrous alcohol	1·80
Hydrochloric acid	2·07
Nitric acid	2·07
Oil of turpentine	2·58
Distilled water	3·40
Solution of ammonia	3·60
Solution of carbonate of ammonia .	4·56

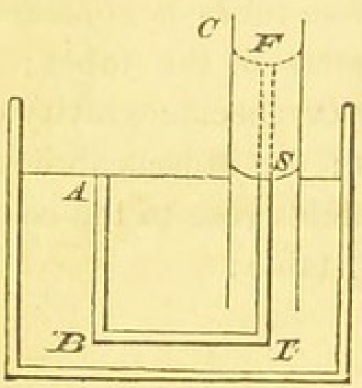
18. Capillary attraction comes into play equally between two plane surfaces immersed in fluids, as in the case of tubes. If two plates of glass, A B, touching at C, and separated at B at a very small angle, be plunged into a trough, D, filled with coloured water, the fluid will, after a short time, rise between the plates, attaining the greatest elevation where the glasses are closest approximated; and describing the curved surface well known



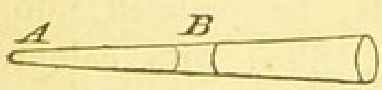
* Diss. physic. experiment. L. B., 1729.

as the hyperbola. The utmost elevation attained by the fluid in this arrangement is one half of that which would have taken place in tubes having their diameters equal to the distance between the plates, and being always inversely as this distance.

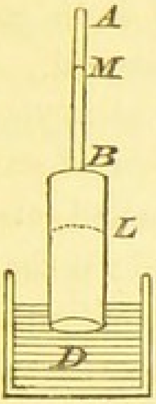
19. When a glass tube is immersed in a fluid, the attractive force of its internal sides determines the curve assumed by the surface of the water, but does not cause its elevation: this is owing to the action of the fluid itself; for let C be a capillary tube immersed in water, the attraction of this hollow cylinder causes the water to assume the concave surface, S; let ST be an infinitely thin column of water, perpendicular to the centre of this curve, and corresponding to the axis of the tube, and AB be a similar column of water connected by an imaginary transverse portion BT; now, if no attraction were exerted at S, the two branches, AB, ST, of this fluid rectangle would counterbalance each other, and no elevation ensue; but the fluid surface at S being attracted by the interior of the tube, the perpendicular pressure of the fluid column at T becomes less than that of AB at B; accordingly, AB preponderates, and presses through BT, the base of the column, ST, and forces it to ascend in the tube to a certain elevation, as at F, and finally it remains suspended there, bounded by the same concavity produced by the attraction of the parietes of the tube.



If a drop of water be placed in the wider end of a conical glass tube, as at B, it will rapidly move towards the smaller end, A: the drop on being placed in becomes bounded by two concave surfaces, of which that nearest the apex of the tube is the most curved; the drop, therefore, moves towards the apex in consequence of the attraction of the sides of the cone



for the water; being, according to Laplace, inversely as the radius of the curve terminating the fluid column.

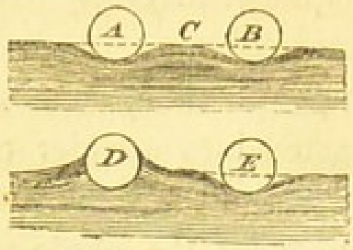


21. Let ABD be a compound tube, consisting of a fine bored tube inserted into a wider one, immerse this in water, the fluid will rise to a certain elevation as L: now let the whole tube be filled with water, and immerse it again; it will be found that the fluid will fall to a certain point in the finer tube, as M, and there remain suspended as perfectly as if the whole tube had been of the same diameter as the part AB. On refilling the tube, and immersing the end, A, instead of D, in the water, the fluid will rapidly fall, and finally attain an elevation equal only to that produced if the whole tube had been of the same diameter as the wide portion, BD.

By means of this capillary attraction, oil is raised in the wicks of lamps, water in bibulous paper, cotton threads or any porous substance immersed therein; in fact, every phenomenon in which fluids insinuate themselves between particles of solids at small distances are referrible to this force.

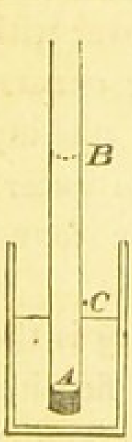
22. If, instead of using water in the experiments just detailed, a fluid incapable of moistening the surfaces of the solids immersed be employed, the converse of the phenomena are observed, repulsion taking place instead of attraction: thus tubes, or glass plates immersed in mercury in their ordinary state, cause a depression instead of elevation; or, if water be used, and the tubes greased or rubbed over with resin, or, still better, lycopodium, the same thing occurs. This repulsion at small distances is well observed by rubbing the hand over with lycopodium, and immersing it in water; on withdrawing it, not a drop of water will be found adhering to it.

23. A class of phenomena referrible to *capillarity* is the apparent attraction and repulsion of small bodies floating on water, and placed at small distances; if one of the bodies



only be composed of a substance capable of being moistened by water, mutual repulsion, and if both are incapable of being moistened, as two balls of wax, mutual attraction ensues. If the balls AB be of wax or cork, rubbed with lycopodium, the water is repelled, and two depressions in which the balls lie are produced; if they are then placed sufficiently near each other, the repulsion of the opposed surfaces of the balls exerted on the water at *c* will render it concave, and the balls, by the lateral pressure of the water beyond, will be pushed together, and appear to attract each other. In the second case, if the ball D be of clean moistened cork and E of wax, the reverse takes place, the water being raised by attractive force on all sides of the first, and repelled by E; consequently, on the balls being placed in contact, they appear to repel each other from D attracting fluid, which repels and is repelled by E, the latter being incapable of being moistened by the water.

24. Closely allied to capillarity are the phenomena of endosmose and exosmose, discovered by Dutrochet. Whenever two liquids of different densities are separated by a membranous or porous partition, two currents become established, one from a current of fluid proceeding from within to without, (exosmose, εκ and ωσμος, impulse,) the other in the contrary direction, (endosmose, ενδον and ωσμος). If a glass tube closed at



one end with a piece of bladder, A, be filled with a solution of sugar, salt, &c. and immersed in a vessel filled with pure water, the fluid will rapidly rise in the tube B, the water having entered through the bladder by endosmose, and adding to the contents of the tube cause the fluid to be elevated much above its former level; if, now, the conditions be reversed, syrup being placed in C and water in B, exosmose will occur, by which the tube B will become nearly emptied. As a general rule, liable, however, to several exceptions, it appears that fluids of less specific gravity have a tendency to pass through membranes, and porous bodies, to mix with those of greater density, and consequently dilute them.*

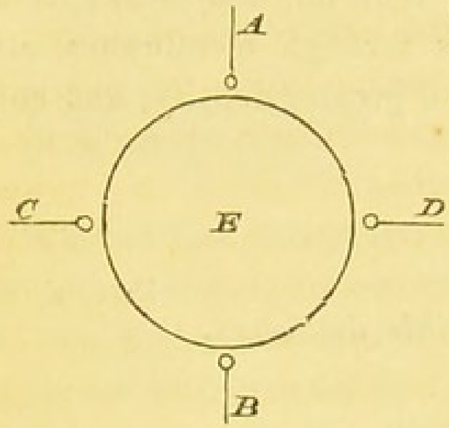
Attractions at sensible distances.

GRAVITATION.

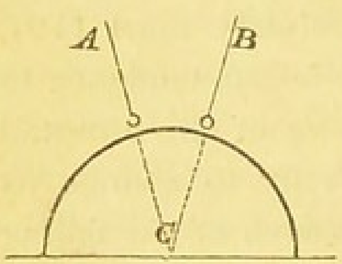
25. When any substance as a stone, &c., is permitted to fall from the hand, every one knows that it rapidly reaches the floor, and does not rise towards the ceiling nor move laterally towards the walls of the room. A stone being mere inanimate matter and consequently absolutely inert (10), this phenomenon cannot depend upon any *innate* tendency to reach the lower part of the room, as one of the essential properties of matter is its utter incapacity to change its position, consequently the simple phenomenon of the falling of any body towards the earth must arise from the exertion of an attractive influence or force emanating from the latter, and to this the name of *Gravitation* is applied in consequence of its causing that effect which we recognize by the term *weight*: the weight of any substance being merely a measure of the attraction of the earth for it. This form of attraction is exerted not only at comparatively small, but at vast distances: thus, this force acts as effectually on the planet Herschel at the distance of 1,800,000,000 miles as on the falling apple in which Newton is said first to have recognized its existence. If a mass of lead be suspended to a string it will, as every one knows, when left free to move, point towards the earth; now the same thing occurs in India, in America,

* Nouv. Recherch. sur l'Endosmose, &c. par M. Dutrochet. Paris, 1828.

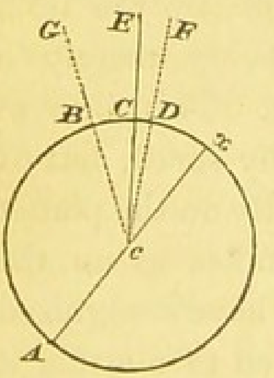
and at our antipodes, proving at once that the lead does not obey a *natural tendency to fall*, for the plummets, AB, point in opposite directions, as also do CD, according as they are situated at the opposite poles or at east and west; all pointing towards the centre, E, of the earth.



26. Gravitation, in common with other attractive forces, obeys most strictly the general law already announced (12), and must always be considered as acting from the centre of the spherical body from which it emanates. From this circumstance it is impossible for two plumb lines freely suspended to hang perfectly parallel. Let A and B be two lines furnished with leaden balls, they will point towards the centre, C, of the earth, and of course, instead of being perfectly parallel, will form an angle with each other which at small distances is so slight that it may be almost neglected in practice although it can never entirely vanish.



Let ABCDX be a section of the earth at the meridian of Paris, and AX its axis of rotation. Paris will be situate at C, and a plumbline there will point in the direction ECc. Dunkirk will be at D at an angular distance of 2° 11′ 6″ from Paris, and its plumbline will coincide with FDc. Barcelona will be at B at an angular distance of 7° 28′ 29″ from Paris, and a plumbline there will coincide with the line GBc, forming an angle of 9° 39′ 35″ with a similar plummet at Dunkirk.*

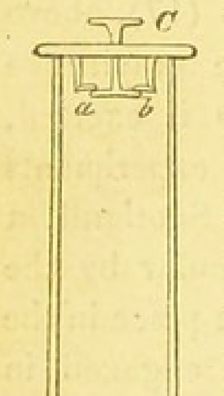


* Pouillet, Elements de Physique. Paris, 1837; p. 62.

27. The intensity of the attraction of gravitation increases, not only when the mutual distances of the attracting bodies are diminished, but also in the ratio of the quantity of matter contained in them; and being *mutually* exerted between bodies, they always move to meet each other; hence when a book or a stone falls towards the earth, the latter rises to meet it: this motion is of course almost infinitely small, because the attraction of these bodies for the earth being, *cæteris paribus*, in the ratio of their masses, the enormous preponderance in favour of the earth would prevent its moving an appreciable distance to meet the stone, whilst it would be sufficient to enable our globe to attract the latter at a distance of several millions of miles. As a necessary consequence of this mutual attraction, elevated buildings and mountains might be expected to gravitate towards each-other, an effect prevented by the superior attraction of the earth which tends to keep them on their bases, and by the attractions at insensible distances which firmly binds their integrant portions together; for whenever gravitation and cohesive or capillary attraction are opposed, the latter within the limits to which they are confined are most energetic, instanced in the ascent of fluids, in tubes (17), above their former level, and in opposition to the gravitative attraction of the earth. Still lateral attraction is exerted, for Dr. Maskelyne has proved that in a set of experiments performed near the mountain Schehallion in Scotland, a plummet was really drawn from the perpendicular by the attraction of the mountain; the same thing took place in the researches of the French astronomers, whilst engaged in America in determining the measure of the meridian, numerous sources of fallacy, arising from the lateral gravitation of their instruments towards the surrounding mountains, opposing themselves to the correctness of their results.

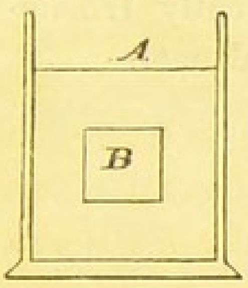
28. If no material obstacle interfere to check or impede the fall of bodies towards the earth, the attraction of the latter will cause them to fall with equal degrees of velocity, so

that all bodies falling from the same elevation at the same instant will reach the earth together. Daily experience appears indeed opposed to this, as heavier bodies seem to fall with greater velocity than lighter ones, and this on superficial reasoning might be expected, as attraction increases in proportion to the mass of matter. This objection vanishes when we recollect that, as matter is *inert*, force is required to set it in motion, and the *quantity of inertia being as the quantity of matter*, it follows that if an attracting force equal to four is sufficent to draw a quantity of matter equal to 100 pounds to the earth, that four times that force will be necessary to draw 400 pounds with the same velocity, for as the mass of matter increases, its resistance to alter its state or position increases: a consequence necessarily following from the observations already made on the inertia of matter (10); and hence all bodies falling from the same height will occupy the same time in falling through a given space. The apparent exception in the case of an extremely light body, as a feather, paper, gold-leaf, &c. which, instead of falling directly towards the earth, float in the air and descend by a circuitous route, admits of ready explanation; for this deviation from the direct course arises from the resistance of the medium in which they move opposing itself to their direct downward motion; if this opposition on the part of the atmosphere be counteracted by compressing these light bodies into small bulks, as by rolling the paper or gold-leaf into a ball, then they will descend with equal velocity with heavier bodies; this is still better shown by placing a piece of metal and a feather on the brass slides,



ab, fixed at the top of a tall glass receiver; on turning the key C, the slides give way and the metal and feather fall, the former reaching the plate D sooner than the latter; replace them and exhaust the air by means of an air-pump, on now turning the key C, the feather and piece of metal will fall, and be found to reach the bottom, D, at the same instant of time.

29. The ascent of vapours, and balloons into the air, like that of light bodies, as corks in water, is produced by the attraction of gravitation ; for this attraction being greatest in proportion to the quantity of matter, the denser bodies, as the atmospheric air or water, are drawn forcibly downwards ; and those containing a less quantity of matter in a given bulk, as the balloon in the former case and cork or wood in the latter, are forced to rise by the denser fluid bodies sinking beneath them.



Let the vessel A be filled with water, and a solid body, as B, be placed in it, both the fluid and the body B will be attracted by the earth ; and if B be denser than the same bulk of water it will be attracted by the earth and will sink ; but if it be less dense than an equal bulk of water, the latter will obey the gravitative attraction of the earth, and B will be forced to rise to the surface. Thus the floating of light bodies in fluids of every description, is a direct and legitimate consequence of the law of gravitation.

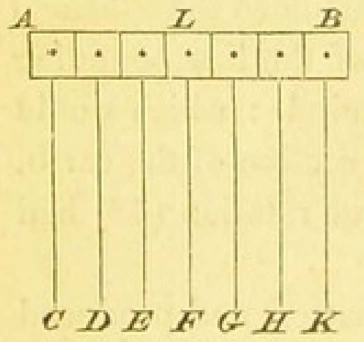
30. The spherical form of our earth and the planets of our system appears also to result from this law ; for as attraction is equal at equal distances, and emanates from the centres of the masses, we may conclude, that the earth, when in a fluid or semi-fluid state, must necessarily have assumed the spherical form ; because no figure has every part of the line bounding it equidistant from the centre except a circle : which would have been the exact figure of a meridian section of the earth, if disturbing causes arising from its rapid rotation (43) had not interfered.

As weight is an *acquired* property of matter, and produced by an attractive force (25) emanating from the centre of our earth, it follows that a mass of matter would not appear so heavy on the top of a lofty mountain as on the earth's surface, because it will be there further removed from the centre of the earth. And accordingly it is found that a mass of lead, weighing 1000 pounds on the level of the sea, loses two pounds of its weight on being elevated four miles above the surface; and if carried to the surface of the moon, and thus be removed 240,000 miles from the earth, it would not weigh above five ounces.

For this reason, bodies weigh ~~less~~ heavier near the poles than at the equator, on account of the former being nearer the centre of the earth than the latter; and if it were possible to place any body in a cavity at the centre of the earth, it would be equally attracted on all sides, and consequently remain suspended in space, like the fabled coffin of Mahomet.

CENTRE OF GRAVITY.

31. A little reflection on the nature of gravitation will indicate the existence of a point in every substance, at which the attraction of the earth for every portion will be equally balanced; and which if supported by mechanical means, will place the whole body in a state of stable and firm equilibrium. This point is termed the *centre of gravity* or *centre of inertia*, as it is the spot where the whole vis inertiæ of the mass may be supposed to be concentrated. Let AB be a bar of any substance divided into seven imaginary parts, the dots in the centre of each representing the centre of gravity of each portion, now the attraction of the earth for each of these parts may be represented by a series of parallel right lines, CDEF, &c. and if each component portion be of equal bulk and density, the attraction of the earth for each will be equal; under these circumstances, three lines of attractive force of

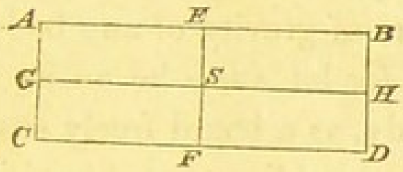


equal intensity are situated on each side of L; and if a sufficiently strong prop be fixed in the direction LF, the whole body will be supported. The support LF must be strong enough to resist the attraction of the earth for the seven portions of AB, represented by the seven lines, which attraction is of course equal to the *weight* of the bar. The spot in the centre of the portion L of AB is called the *centre of gravity of the whole bar*, and, as at this point the attractive force of earth, represented by CDEGHK, may be supposed to be concentrated in the centre line F; it is also the *centre of parallel forces* (87).

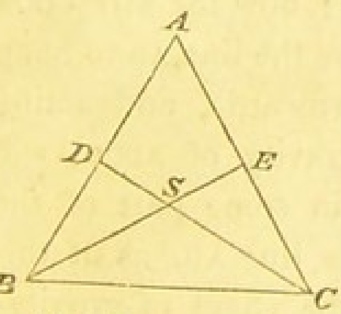
Mode of determining the centres of gravity of differently formed bodies.

32. (A.) The centre of gravity in a right line, composed of similar particles of matter, is its middle point. In the line AB, the point C is the centre of gravity.

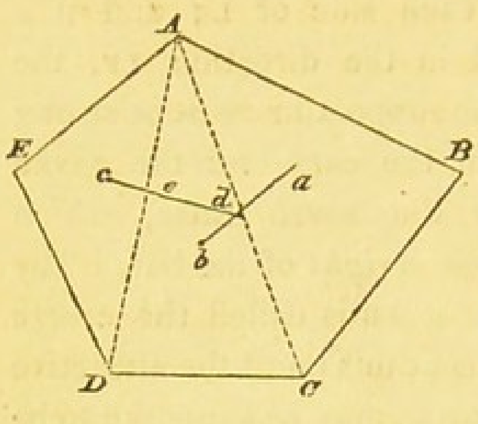
(B.) The centre of gravity of a parallelogram is the point where lines bisecting two of its sides intersect each other. In the figure ABCD, bisect AB and CD by the lines EF GH. The point S, when these lines intersect, corresponds to the centre of gravity.



In a triangle, as ABC, the centre of gravity is found by bisecting AC, and AB at DE, connect DC and BE; the point S, where these lines intersect is the centre of gravity.



(C.) In any other figure bounded by right lines, the centre of gravity may be found by dividing it into triangles, and



finding the centre of gravity of each. Thus let ABCDE be the figure in question, divide it into the triangles ADC, ABC, and AED, find the centre of gravity of each in the manner already described, and let *abc* be these points, then join *ab*, and take

db : *ad* :: ABC : ADC,

and *d* will be the centre of gravity of ABC, ACD. Then join *dc*, and take

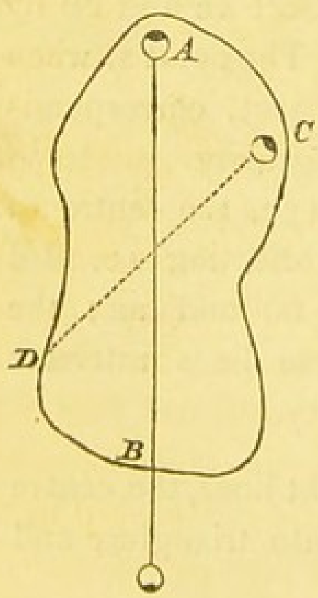
ce : *ed* :: (ABC + ACD) : AED,

and *e* in the middle of the line *cd* will be the centre of gravity of the whole figure.

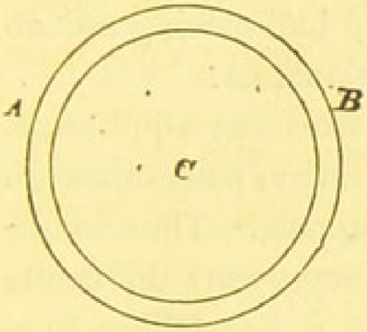
(D.) In a circle the centre of gravity is in its geometric centre; and in an oval, at that point where its transverse and longitudinal diameters intersect.

In all these cases the density of the matter composing the figures is supposed to be uniform, and its thickness inappreciable.

33. If a body be freely suspended by any point, it will remain at rest when a perpendicular line let fall from that point passes through its centre of gravity. This law affords a ready mode of determining the centre of gravity of any body

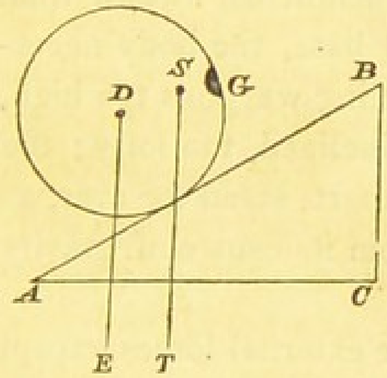


by experiment; for let ABCD be an irregular-shaped body, as a board freely suspended at A, a plumbline, AB, hanging on the same support; now the attraction of the earth will cause the line AB to hang perpendicularly downwards, and acting on the centre of gravity of ABCD, will cause that to fall in some part of the figure covered by the line AB, as at this point or centre all the effect of gravitation may be supposed to be concentrated (31). With a pencil draw a line, AB, on the board, and suspend it with the plumbline from another point, as C; the force of gravitation will now cause the board to assume a state of rest in another direction, still having the centre of gravity in the course of the vertical line described by the plumbline: let this be CD, and the point where ABDC intersect each other corresponds to the centre of gravity of the figure ABCD.



34. The centre of gravity is by no means necessarily placed in the body itself; in a ring for example, as AB, this point will be the centre, C, and consequently in the space midway from every portion of the solid.

35. If a body be not of uniform density, the centre of gravity is not situated in the places above described; in an homogeneous circular figure it corresponds, as above stated, with the geometric centre: but in one of unequal density in different parts, it becomes eccentric, often considerably so.

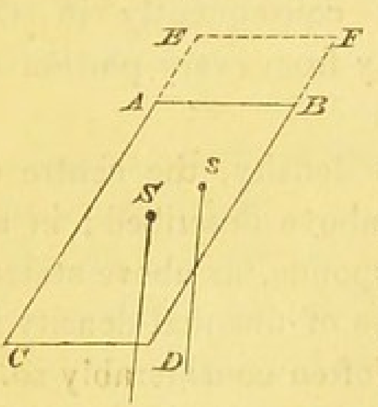


Let ABC be an inclined plane, and a circular figure, D, be placed upon it; if this be composed of matter of equal density, D will be the centre of gravity, and being attracted by the earth in the direction DE, falling below the point supported by the plane, the circular body will necessarily roll down.

Let the portion G be composed of some dense matter, as lead, the remaining portion being of wood, as alder; then a bulk of the latter, weighing 800 grains, will correspond in size to a mass of the former, weighing 11,350 grains: these numbers representing the specific gravities or densities of these two bodies. The attraction of the earth will now act very differently on the circular figure D, for the centre of gravity will no longer be at the geometric centre, but at a point nearer G, as S; it will act on S in the direction ST, causing it to assume the lowest point, the point S will obey this attraction, and the circular figure D will roll up the inclined plane; remaining at rest when a line let fall from the centre of gravity passes through the point supported by the plane.

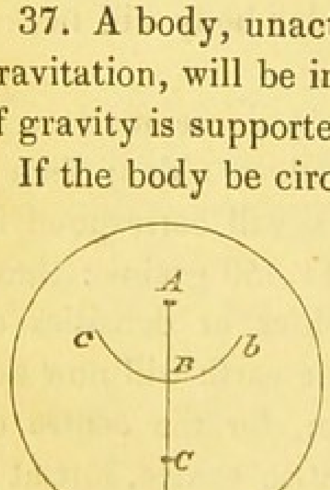
The analogous phenomena of a double cone moving up a double inclined plane, and of a billiard ball moving up two inclined grooves, admit of a similar explanation.

36. No body can be in a state of permanent equilibrium unless a line, falling from its centre of gravity, passes through the point of support. Thus in the figure ABCD, S represents the centre of gravity, and a line falling from that passes through the base, which is supported by the table, the figure therefore stands safely; but place on its summit another piece, AEFB, the centre of gravity will be raised to *s*, and as a perpendicular drawn from that point falls beyond the supported base, the body necessarily falls. Hence the danger of loading waggons too high, and of building walls, if necessarily inclined, too lofty; the leaning tower of Pisa may, accident apart, stand for ever, as long as a perpendicular line drawn from its centre of gravity falls within its base.



37. A body, unacted upon by other external forces except gravitation, will be in a state of *equilibrium* when its centre of gravity is supported.

If the body be circular, and B its centre of gravity, it will be in a state of *stable* or *steady equilibrium* if supported by an axis passing through A, for a perpendicular falling from A will pass through the centre of gravity, and if the body be moved it will, after a few oscillations, in which B will describe the circular arc *cb*, re-



cover its former position. If, then, the axis be passed through B, the body will be in a state of *indifferent equilibrium;* for the point of support corresponding with the centre of gravity, it will remain at rest in whatever position it be placed. Lastly, if an axis be passed through C, the body will be in a state of *unstable equilibrium,* for it can only retain this position as long as a perpendicular from B passes through C; and as soon as the slightest deviation occurs, on the application of the smallest force the body will move round, until B falls under the point of support. Thus, for a body to be in a state of *steady equilibrium,* its centre of gravity must occupy the lowest possible point.

CHAPTER III.

ON MOTION. (GENERAL DYNAMICS.)

38. In the preceding chapters we have confined ourselves to the consideration of matter in a state of rest; we have next to investigate the properties of matter in motion, constituting part of the science of Dynamics.

By motion we understand the act by which a body changes its position; it has been divided into several species: thus a body is said to be in *absolute* motion when it is actually moving from one part of space to another, instanced in the movements of the planets; and to be in a state of relative motion when it is moving with respect to some other body and at rest with regard to another: thus a man standing in a sailing vessel is in motion with relation to the shore, and at rest in relation to the several parts of the ship; in this case also his motion is said to be *common* with that of the vessel. Besides these, there are some other divisions of motion of importance to understand: thus the motion of a body is *uniform* when it passes over equal portions of space in equal times; it is *accelerated* when the successive portions of space passed over increase, and when they diminish it is said to be *retarded*, and when this increase or decrease of movement is constant, the motion is said to be *uniformly accelerated* or *retarded.* The motion of any body is *swifter* or *slower* in proportion as the space passed over in a given time is greater or less. The degree of rapidity with which a body moves is termed its *velocity*, and is measured by the space passed over in a given time.

39. In consequence of the *inertia* of all bodies, force must be applied to cause them to assume motion; if it be merely intended to cause the body to move in the same horizontal plane which it previously occupied, the applied force must be sufficient to overcome the innate resistance of the body to any alteration in position, or *inertia*, and the friction of the supporting body; but if it be intended to place the body on a higher horizontal plane than it previously occupied, the applied force must be sufficient to overcome also the attraction of the earth, or force of gravity.

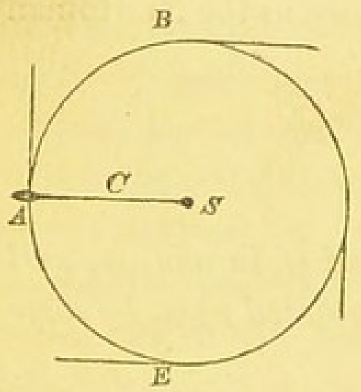
40. The simplest principles to which the phenomenon of motion could be reduced have been arranged by Newton in the form of three axioms or laws; well known as the Newtonian laws of motion.

LAW I.

A body at rest will continue at rest; and if in motion, will continue to move in a right line, unless acted upon by some external force.

This law is a necessary consequence of the *inertia* of matter (10); the second part, however, referring to a moving body never assuming a state of rest until acted upon by external force, might at first be doubted; but a little reflection on the commonest phenomena of moving bodies will dispel this doubt and demonstrate the truth of the Newtonian axiom. The chief invisible external causes checking the motion of bodies are, 1. *Friction.* If a ball be thrown along a common road, its motion from its encountering so many obstacles, becomes obstructed and it soon stops; on a smooth bowling-green, there being less friction, the ball moves to a longer distance; and still farther on a smooth sheet of ice or level pavement, from the great diminution of friction. 2. *Resistance of the atmosphere.* This has been already referred to as a powerful cause in checking motion (28); it may be very satisfactorily proved by causing a wheel accurately balanced to rotate in air, and in the vacuum of an air-pump; and it will be found to continue in motion for a much longer time in the latter than the former. 3. *Gravitation.* This is by far the most important source of opposition to the continuance of motion, for whether a body be projected vertically upwards, or horizontally: the attraction of gravitation will ultimately cause it to stop and fall towards the earth.

41. In consequence of the *inertia* of bodies causing them to persevere in rectilinear motion, it is found that when revolving in a circle they constantly endeavour to recede from the centre: this is termed the *centrifugal* or centre-flying force. If a ball fixed to a cord, C, be made to revolve rapidly in a circle from a fixed point, S, as a centre, it will describe the circle ABE; if whilst rapidly moving, the cord C be cut with a sharp knife, the inertia of the ball will cause it to continue in motion, not however in a circle but in a right line corresponding to a tangent to the circular orb it described whilst the line C was entire. The force which caused A to fly off in the direction of a tangent is the *centrifugal* force; and the cord C, represents the direction of the *centripetal* or centre-seeking force. Thus, considering the circle to be composed of an infinity of planes, the ball will tend to follow the direction of one of these planes and rush off at a tangent to the curve; this circumstance taking place the instant the force which binds A to the centre is overcome.



42. We see magnificent examples of this force in the revo-

lution of the spheres of our universe: here the earth and other planets revolve round the sun as a centre with enormous velocity, everywhere tending to rush off into infinite space in the direction of a tangent to their circular orbits, a state of things of course equivalent to universal desolation and destruction, and prevented only by a powerful centripetal force; here represented by the gravitative attraction of the sun by which all the planets tend to gravitate towards his centre. Equally balanced between these opposing forces, the elements of our universe have revolved for myriads of ages around the great centre of our system, presenting a spectacle of infinite harmony and wisdom.

43. On our own globe we have a remarkable instance of the effects of this force, from its revolving on its own axis at the rate of 13·5 miles in a minute; an energetic centrifugal force becomes generated at the equator, by which portions of the earth tend to rush off into space; this is prevented by the *centripetal* force of gravitation acting from the centre of the earth. Still this has not been without its influence, for at an early epoch, probably during a semi-fluid state of our globe, a considerable bulging out occurred at the equator, and a corresponding flattening at the poles; so that the equatorial diameter of the earth is 17 miles greater than its polar diameter. On this account bodies weigh less at the equator than at the poles, 1000 pounds at the latter corresponding to 995 at the equator, from the increased distance from the centre of the globe.

The projection of a stone by a sling; heaving the lead at sea; the scattering of drops of water from the wet revolving carriage wheel, or housemaid's mop; are so many familiar examples of this force.

LAW II.

44. *Change in the direction of motion is always proportioned to the force applied, and will take place in a right line with the impressed force.*

Having in the preceding observations, learnt that all motion must result from the application of force, we now find that such motion will be proportioned to the force applied; and thus, if a force equal to 2 produces a certain amount of motion, twice as much will be produced by a force of 4, and three times as much by a force of 6. If the direction of the force be horizontal, the movement will be in that direction; and if oblique, the direction of the motion will be equally so. The motion will be increased or diminished in the same proportion as the applied force.

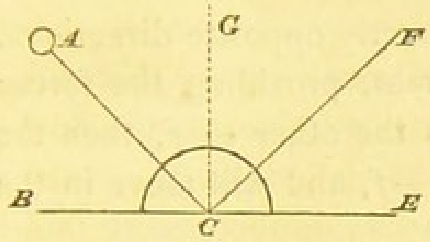
LAW III.

45. *All action is attended by its corresponding reaction, equal in force and opposed in direction.*

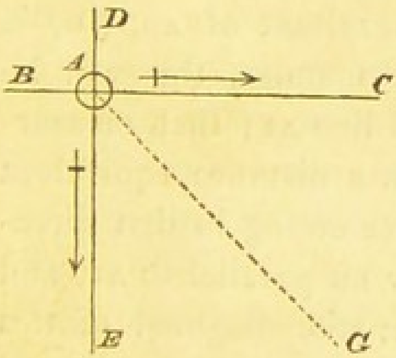
The existence of this law is so obvious that a very few examples will be sufficient to prove its universality. If a person presses a stone with his finger, he experiences a resistance arising from the reaction of the stone producing a counter pressure. A horse drawing a load forwards, is pulled backwards by the weight to which he is connected. A bird, in the act of flying, strikes the air downwards with its wings, and produces a reaction sufficient to support itself in the medium in which it lives. In swimming, a man strikes the water downwards, and its reaction raises and causes him to float. In firing a rifle, the exploding powder, which gives to the ball its fatal velocity, produces the recoil of the piece.

46. This law is also the cause of the well-known phenomenon of the *reflexion of motion*. If any body, as a marble or any other tolerably elastic body, be thrown against a

fixed substance; it strikes it with a certain degree of force, and the reaction of the fixed body throws the ball back again with equal force, providing no opposing causes interfere. If the ball be projected in a direction perpendicular to the plane of the fixed body, the reaction will drive it back in the direction of the path it described whilst advancing towards it; but if it move obliquely the reaction will reflex it with an equal obliquity, but in an opposite direction. Let A be the moving body projected in the direction AC against the fixed obstacle C; the reaction of the latter will reflex the ball in the direction CF, forming an angle with the plane of the fixed body, equal to that formed during its approach to C. The angle formed by the line AC with the perpendicular GC is called the *angle of incidence;* and that by the line FC with GC, is called the *angle of reflexion;* and as the angle AGC is equal to the angle GFC, we deduce the general law, that the *angle of incidence is always equal to the angle of reflexion;* a law applying not only to the movement of ponderable but of imponderable matter, as light.



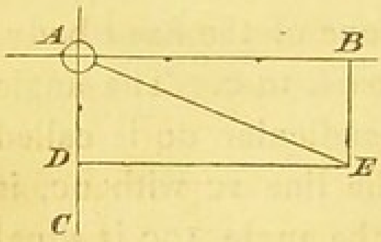
47. From the Newtonian laws of motion we learn that the application of one force can only produce movement in a straight line; and that two or more forces are necessary to produce curvilinear motion. We have next to consider the effects resulting from the simultaneous actions of two or more forces on bodies free to move.



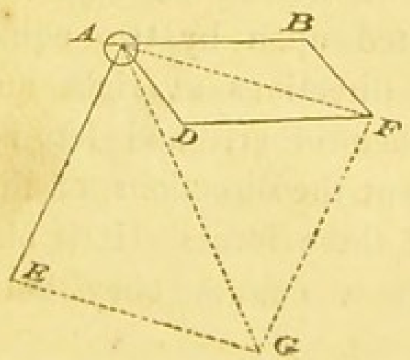
Let A be a ball of any substance acted upon by two equal forces in directions at right angles to each other, and let BC DE represent the directions of the actions of these forces. It is obvious that A cannot obey both these forces at the same instant, without separating into two portions; it therefore takes a path midway between them in the direction of the dotted line AG; which is termed the *resultant* of the two separate forces BC, DE.

If the two forces act on A, in directly opposite directions, the ball will of course remain at rest, providing the forces are equal; but if one = F exceeds the other = *f*, then the ball will obey the excess of force F—*f*, and will move in the direction in which F acts.

48. When the forces are unequal, the resultant path of the ball may be readily determined; let, as before, A be the ball, acted upon by two forces at right angles to each other; let AB represent the direction of one, and AC of the other force. Suppose that the force acting in the direction AB is equal to 3, and that in the direction AC to 2. On the line AB, take off from a scale of equal parts the distance 3, and on AC the distance 2. Describe DE parallel to AB, and BE parallel to AD; then join AE, and this line will be the path taken by the ball A, and is the *resultant* of the forces AB, AD.

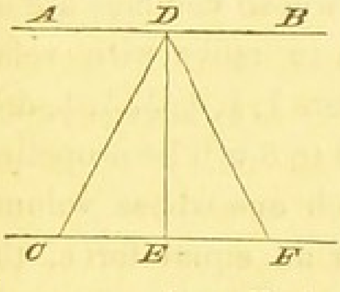


49. When three or more forces act upon a body, their *resultant* may be found in a similar manner; for having found the resultant of two forces, in the manner already described, adopt this for the side of a fresh parallelogram, the other being furnished by the line of direction of the third force. Thus, if A be acted upon by the forces AB, AD, AE; find the resultant of AB, AD, in the usual manner, this will be the dotted line AF; then measuring on AE a distance equivalent to the force acting in that direction, draw EG parallel to AF, and FG to AE; the diagonal of this parallelogram AG will be the *re-*



sultant line, in which the combined action of the three forces will ultimately act.

50. In consequence of the *resultant line* pointing out the ultimate effect of all the forces exerted, this case is termed *composition of force* or *motion;* and the quadrilateral figure described by the lines in the above figures is termed the *parallelogram of forces.* Conversely as we obtain a *composition of force*, by the simultaneous action of two in different directions; so we can, by what is termed the *resolution of force* or *motion*, resolve or refer the production of certain rectilinear motions to the simultaneous exertions of two different effects. Thus, in the case already mentioned (46), when a moving ball strikes a fixed obstacle, neither being perfectly unelastic, the angles of reflexion and incidence are equal; the reflexed motion DF of the ball C, after striking D, may be accounted for. For the force by which C moves obliquely to D may be resolved into two, one acting in the direction CE, parallel to the plane, and the other, DE, perpendicular to it. As both these forces are virtually in action when C strikes D, the reaction of the latter will develope both, and tend, the one to move the ball in the direction DB, the other in the direction DE. It being impossible for the ball to obey both forces simultaneously, it follows the resultant line DF, which forms, with E, an angle equal to that of CDE.



51. In the resolution of forces, the whole amount of force exerted is necessarily increased, for in the last example the force which propels the ball C to D is resolved into CE, ED, which together are greater than CD; the estimated effects of forces, however, do not become affected by either composition or resolution, when estimated in given directions. (*Wood's Mech.* 66.)

52. Illustrations of the action of one force on a body are too familiar to require notice; of two forces, we have an

example in a boat tending to be carried westward by the tide, whilst the boatman, by the aid of his oars, attempts to direct its course northward; supposing both these forces to be equal in intensity, the boat proceeds in the direction of the diagonal of a parallelogram, two of whose sides represent the direction of these forces, or north-west. A steam-vessel, whose paddles tend to propel the vessel northward, whilst the wind blows eastward, and the tide running in a third direction, illustrates the application of these forces; for the vessel, not being able to obey all three forces simultaneously, sails on her way in the direction of a resultant line of the whole.

53. When forces of equal intensities act on bodies free to move, they cause the latter to move with velocities, which are in the inverse ratio of their masses, or quantity of matter composing them. So that if equal charges of exploding powder be made to act upon bullets, whose volumes are as 1, 2, 3, 4, 5, 6, &c. it will cause them to move with velocities varying reciprocally as the numbers 1, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{5}$, $\frac{1}{6}$, &c. so that the bullet whose volume is equal to 5 will be propelled with a velocity one fifth of that which one whose volume is equal to 1 is projected; hence, for an equal force, the masses of the projectile multiplied by the velocity gives the same number, and this is termed the *quantity of motion*; and a force double or triple that of any other will produce two or three times the quantity of movement. From these facts the following laws have been deduced.

(A.) Forces are to each other as the quantities of motion they produce, or as the masses multiplied by the velocities.

(B.) For equal masses, the forces are to each other as the velocities they produce.

(C.) For equal velocities, the forces are to each other as the masses on which they act.

54. All the laws of uniformly accelerated motion are comprised in the following formulæ, by the aid of which we can calculate results of very considerable importance.

Here t = the time occupied by the movement of a body.
g = the velocity acquired after a second of time.
v = the rapidity of motion acquired after the entire time t.
s = the space passed over by the body in the time t.

$$v = gt, \text{ and } s = \frac{gt^2}{2}.$$

By these formulæ it is obvious that any two of the four data being given, the other two are readily found.

CHAPTER IV.

EFFECTS OF GRAVITATION.

55. Among the forces which are the most energetic in producing motion on the surface of our globe is the attraction of gravitation (25); this force, whilst acting on bodies under its influence and approaching the earth, is an uniformly accelerating force, becoming as uniformly retarding on bodies receding from the earth; so that a body acted upon by it, passes through different portions of space in different times, and, whilst approaching the earth, would each instant pass through a greater space than that which it traversed in the preceding instant of time. If a ball be let fall from the hand, it can be readily caught during the first few inches of its path, but its velocity afterwards so rapidly increases, that it cannot be intercepted by the most agile arm without difficulty. Even if the descending body fall obliquely, still the same rapid increase of velocity is perceived; this is well illustrated by the falling of bodies down steep descents, or long inclined planes: for the first few yards the mass appears to move slowly, rapidly,

however, it increases in velocity, and, as well illustrated by the fall of a granite block from an alpine ridge of rock, or of the more terrific avalanche acted upon by the increasing intensity of gravitation, it tears its hurried flight through almost any obstacle it encounters.

56. A body left free to move, and acted upon directly by the force of gravitation, all opposing forces being excluded, falls in the latitude of Greenwich at the rate of 16·0954 feet in a second of time, acquiring by this motion a velocity of 32·1908 feet, or 386·2894 inches per second. The space traversed by a falling body in a second, is very nearly equal to 16 feet 1 inch; which is sufficiently correct for ordinary calculations, and to enable us to avoid decimals, which are very inconvenient, unless we use logarithms to lessen the number of figures.

57. When a body sufficiently dense and compact to permit us to disregard the opposition of the medium traversed by it, is acted on by gravitation, it is found that *the spaces described by a falling body increase as the squares of the times increase;* thus calling $16\frac{1}{12}$ feet $= g$, we find that in

2 seconds	$(2^2 = 4) - 1 = 3g$,	in 2d second of time.	
3 ..	$(3^2 = 9) - 4 = 5g$,	in 3d	ditto.
4 ..	$(4^2 = 16) - 9 = 7g$,	in 4th	ditto.
5 ..	$(5^2 = 25) - 16 = 9g$,	in 5th	ditto.
6 ..	$(6^2 = 36) - 25 = 11g$,	in 6th	ditto.

Therefore in 1, 2, 3, 4, 5, &c. seconds, the spaces traversed by a falling body are equal to g, × the odd numbers 3, 5, 7, 9, &c. respectively.

Thus, by knowing the time occupied by the falling of any dense body of small bulk, the space traversed by it can be readily calculated; if a bullet falling from a certain height reaches the earth in 3 seconds, we know that

		ft.	in.
in 1 second it traversed		16	1
— 2 seconds ..	16·1 × 3 =	48	3
— 3 seconds ..	16·1 × 5 =	80	5
		144	9;

and the space traversed by it is equal to 144 feet 9 inches. This and similar questions can be more readily determined by means of the formulæ for uniformly accelerated motion already given (54),

$$s = \frac{gt^2}{2}$$

g being equal to 32·1908 feet.

As an example of this formula, suppose we wish to know the space passed through by a body occupying 23 seconds in its descent, then by logarithms

$$\begin{aligned} \log.\ 23^2 &= 2{\cdot}72346 \\ \log.\ g \quad &= 1{\cdot}50773 \\ \hline &\quad 4{\cdot}23119 \\ \log.\ 2 &= \ \ {\cdot}30103 \\ \hline &\quad 3{\cdot}93016 \end{aligned}$$

which is the logarithm of 8514·6 feet, the space traversed in 23″ by the body.

58. A still simpler formula may be adopted, and the calculations easier effected, by squaring the time in which the falling body passes through any space, and multiplying this product by the space passed through in a second of time. This formula expressed algebraically, calling the space passed through in a second or $16\frac{1}{12}$ ft. $= s$, is st^2; this, applied to the last question of a body occupying 23 seconds in its descent, is

$$23 \times 23 = 529, \text{ and } 529 \times 16{\cdot}0954 = 8514{\cdot}4666 \text{ feet;}$$

or by logarithms,

$$\begin{aligned} \log.\ 23 \times 23 &= 2{\cdot}72346 \\ \log.\ s \text{ or } 16{\cdot}0954 &= 1{\cdot}20670 \\ \hline &\quad 3{\cdot}93016 \text{ equal to } 8514{\cdot}6 \text{ feet.} \end{aligned}$$

In this manner the height of any lofty building or depth of a well or shaft may be determined; for by letting fall a pebble from the top of the one, or into the mouth of the other, and noting the number of seconds which elapse before the sound of its striking the ground or water is heard, then—on squaring this number of seconds, and multiplying the product by $16\frac{1}{12}$ feet or, more accurately, by 16·0954 feet, the height of the building or distance of the water from the mouth of the well may be discovered.

59. Also, knowing the time required for the fall of any body through a given space, we can readily discover the velocity with which it moves, and by knowing its velocity we can of course ascertain the time required for its fall through any given space. The following three formulæ will be sufficient to answer every question connected with this subject; v being the velocity of the falling body, and t the time of its descent, the other letters retaining their former value (54),

$$s = \frac{gt^2}{2} \qquad v = 2\,gt \qquad t = \frac{v}{2g}.$$

60. If a body, instead of being acted upon by gravitation alone, be projected downwards with a given velocity per second; this is to be taken into account, and being expressed in feet, and multiplied by the number of seconds, the product is to be *added* to the space, also expressed in feet, which the body would have traversed in the same time, if acted upon by the force of gravitation alone. If, on the contrary, the body be projected perpendicularly upwards, its course being opposed to the attraction of gravitation, instead of being *added*, the effect of the latter is to be subtracted from the space passed through by the projectile, if acted upon by the force of projection only. The following examples will illustrate these statements:

(A.) To what height will a body rise in 3 seconds if projected upwards with a velocity of 100 feet per second?

The space described by force of projection only is . . . . . $100 \times 3 = 300$

Space through which the body would fall if acted upon by gravitation alone during that time (57) . . . . . . $= 144{\cdot}75$

155.25

And the height attained will be but 155·25 feet.

(B.) Where will a body, projected perpendicularly upwards, with a velocity of 80 feet per second, be in 6 seconds?

By force of projection alone, $80 \times 6 = 480$.

.. gravitation alone, $16{\cdot}0954 \times 36 = 579{\cdot}4344$,

and $480 - 579{\cdot}4344 = -99{\cdot}4344$.

The body will therefore be nearly 99·5 feet lower at the end of 6 seconds, than the spot from whence it was first projected; providing no mechanical obstacle be present to prevent this taking place.

(C.) What space will a body pass through in 4 seconds, if projected vertically downwards with a velocity of 30 feet per second?

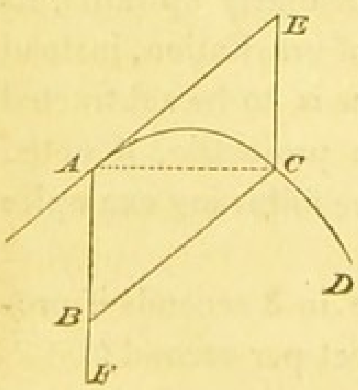
Then by force of projection alone, $30 \times 4 = 120$

.. gravitation alone, $16{\cdot}0954 \times 16 = 257{\cdot}5264$

and $257{\cdot}5264 + 120 = 377{\cdot}5264$.

The body will consequently pass through rather more than 377·5 feet in 4 seconds.

61. If any body be projected in any other direction than vertically upwards or downwards, it will describe a parabolic curve, providing all opposing causes, as resistance of the air, &c. are removed.



Let the body A be projected in the direction AE, and draw AB perpendicular to the horizon; then let AE be the space over which the velocity of projection will carry the body in a given space of time, and AB the distance it would traverse in the same time when acted upon by gravitation alone; now draw BC parallel to AE, and EC to AB completing the parallelogram (47). Then, in consequence of the opposed action of these two forces, the body will be found at the end of a given time at C instead of E, having described the parabolic curve AC, which is the resultant of the two forces (47) of projection and gravitation; the line AE, representing the direction in which the force of projection alone would have carried the body, is a tangent to this parabolic curve, being parallel to the ordinate BC.

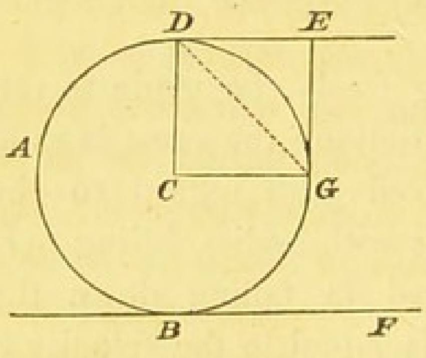
The bullet projected from a gun, a ball from the hand, the stone from a sling, the arrow from a bow, &c. all describe parabolic curves when projected under the conditions already referred to, being ultimately brought to the ground by the all-powerful force of gravitation.

62. If a body instead of moving freely, be made to roll down an inclined plane, free from friction; the same laws of acceleration of motion are observed with regard to the vertical distance passed through, as with bodies falling perpendicularly; the velocity acquired in falling down the length, AB, of an inclined plane is equal to the velocity it would acquire by falling down its perpendicular height, AC. The velocity acquired in falling down the whole length, AB, varies as the square root of the perpendicular height, AC (103).

63. In all these observations, the resistance of the medium in which the body under consideration moves, has been neglected; it furnishes, however, a very important source of opposition to the regularity of motion. *Cæteris paribus*, the denser the medium, the greater the opposition to the passage of the moving body; and in the same medium the resistance opposed to the movement of the body, is proportional to the square of its velocity. It has been demonstrated by Sir Isaac Newton, that when a spherical body moves in a medium at rest, of equal density to itself, it loses half its motion before it has described a space, equal in length to twice its diameter. This resistance is a consequence of the

molecular inertia of the medium, preventing the particles opposed to the moving body acquiring instantaneously a degree of movement corresponding to that of the body. The atmospheric resistance is sufficient to prevent projectiles (61) describing a strictly accurate parabolic curve, as required by the theoretical considerations.

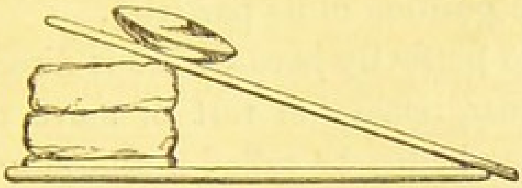
64. All bodies moving through the air have a tendency during their transit, to revolve on their own axis, and where the body is not spherical they tend to rotate round their shortest axis. If the body be of sufficiently regular form, and thrown along the ground, it revolves round an horizontal axis.



Let the ball A be projected along the plane B, with a certain degree of force; this force will act equally on every molecule of A; the friction against the plane at B will prevent its moving with facility, whilst the opposite point D, being free from this opposing force, will tend to move on with all the force which projected the ball; now, as D cannot separate from B; it may be supposed to possess, for an instant only, a degree of velocity greater (because unopposed) than B. Draw DC perpendicular to B, representing the force of friction at B, and DE parallel to BF, to represent the direction of the force of projection, complete the parallelogram (47) by drawing EG and CG parallel respectively to DC, DE, and draw the diagonal DG, which will be the resultant line of direction (50); accordingly, the point D will pass down to G, causing the ball to revolve through one quarter of the circle: another portion coming to D, the same state of things occurs, producing the rapid rotation of A round its horizontal axis, C.

65. If the body be so situated as to have capillary or cohesive attraction (12-16,) acting as the opposing force,

rotation round a vertical axis takes place, providing the body be of convenient form. This is shown by placing a



watch-glass, or plano-convex lens, on a smooth inclined plane, as a pane of glass; having previously dipped the convexity of the watch-glass in water. On the latter sliding down the plane, it rapidly revolves around a vertical axis; whereas, if the plane and glass be perfectly dry, the latter slides down without revolving.

66. All bodies, when moving either under the influence of attraction or any impressed force, oppose a much more considerable resistance to their being stopped, and strike an opposing obstacle with a much greater degree of violence than their mere inertia will account for; this arises from the impetus acquired by the moving body during its passage, —this is termed *momentum*, which, velocities being equal, increases in the ratio of the mass of matter, and in the ratio of the velocities when the masses are equal; consequently, the momentum of any moving body is found by multiplying its mass by its velocity. A light body will, by having its velocity, and therefore its momentum, increased, strike an obstacle with as much force as a heavier one animated with a slower motion. A cannon ball, 3 pounds weight, possessing a velocity of 300 feet in a second, will possess as much momentum, and strike any opposing substance with as much force; as one of 30 pounds moving at the rate of 30 feet per second, for $300 \times 3 = 900$, and $30 \times 30 = 900$.

67. The force with which a moving body strikes another, is termed percussion, or collision; and is the same with momentum. When two moving bodies come in contact, their collision is said to be direct, when a right line connecting their centres of gravity passes through the point of impact.

3

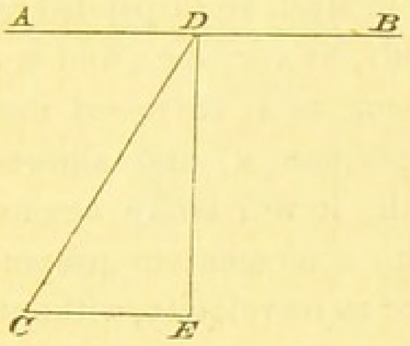
In speaking of the collision of bodies, a substance is said to be perfectly hard, when it is utterly impossible by any finite force to separate or alter the position of its particles.

When the collision of two perfectly hard bodies is direct, they will, after impact, either remain at rest or move on uniformly together. Let these bodies be called A and B, and let A overtake B, both moving in the same direction, then A will continue to accelerate B, and B to impede A, until both have acquired the same velocity, after which they will move on uniformly together; but if they move in opposite directions, and their momenta be equal, they will mutually stop each other, and rest after collision. If the force of A is greater than that of B, the whole velocity of B will be destroyed; and as some of A's will still continue, this will act on B, until they, as in the first case, move on uniformly together. In both cases the common velocity of A and B, after collision, may be found by dividing the whole momentum before impact, estimated in the direction of either motion, by the sum of the masses of matter.

68. When collision takes place between perfectly elastic bodies, the velocity gained by the body struck and that lost by the striking body, will be twice as great as if the bodies were perfectly hard and inelastic. On impact first taking place, the same state of things occurs as in the case of collision of perfectly hard bodies; and as soon as one body has produced the full effect of collision on the other, they both become compressed by the blow, and, recovering their former shape in consequence of their perfect elasticity, react on each other; each body receiving an impulse, equal to that which caused its compression.

69. If a perfectly elastic body impinge upon a hard and fixed plane obliquely, it will be reflexed from it in such a manner, that the angles of reflexion and incidence will be precisely equal: this has been already pointed out (46), but if both the striking body and fixed plane be perfectly hard,

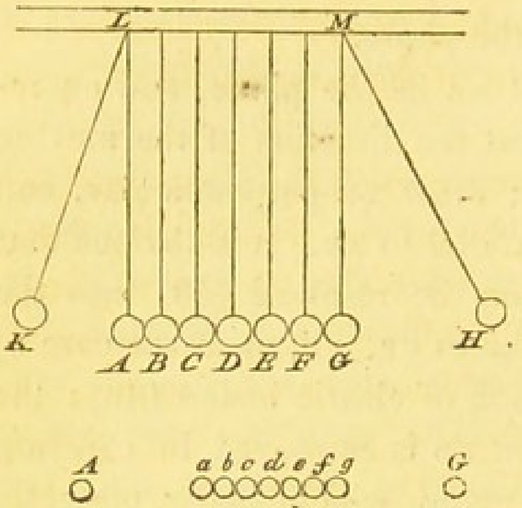
then, after its oblique incidence, the body will not be reflexed, but will move along the plane.



Let AB be the plane, and CD represent the direction of the moving body; draw DE perpendicular, and CE parallel to AB. It is obvious that CD may be resolved (50) into the two forces CE, ED, as in the case of collision of elastic bodies (46); the motion ED is employed in carrying the body directly towards the plane, which, being perfectly hard, annihilates this direct motion. The other motion CE is employed in carrying the body in a direction parallel to the plane, and of course will not be destroyed by the impact; and no force existing to separate, or reflex the body from the plane, it will move along it in the direction DB. In this case, calling the velocity before impact V, and that after, v, we have

$$V : v :: \text{rad} : \cos \angle \text{CDA}, \text{ or } V : v :: \text{CD} : \text{CE}.$$

70. Bodies possessing but imperfect elasticity, as soft substances, oppose more effectually than any others the momenta of bodies in motion, in consequence of their yielding in a greater or less degree to the force of collision without reacting upon it; and thus opposing a gradual resistance instead of a sudden one, as in the case of perfectly hard substances, to the shock of the moving body. Thus receiving, as it were, the force of momentum in several instants of time, instead of but one, and dividing the impetus of the shock: hence a feather bed or sack of wool will stop a bullet much more effectually than a plate of iron, from their *deadening*, as it is popularly termed, the force of the blow.

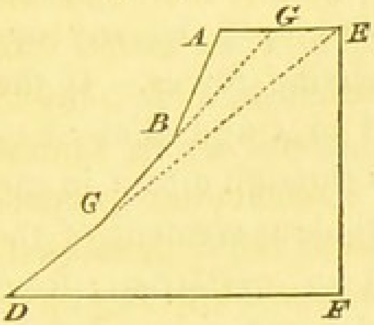


If a number of equal spheres of some elastic substance, as ivory or steel, be suspended by threads, as ABC, &c., and one of them, as A, be raised into the position K, and allowed to fall, it will strike against B with a momentum proportioned to its velocity, without, however, moving in any obvious manner this, or the intermediate balls; but G will start into motion and, all opposing forces being removed, rise to an elevation, H, equal to that of K, so that the angles KLA and GMH will be equal. The ball will then fall and strike F, and A will again be elevated, and so on, the terminal balls continuing this alternate vibrating movement as perfectly as if the intermediate balls were absent, until, from friction and other causes, they cease to move. This curious phenomenon arises from the comparatively perfect elasticity of the balls, for when A strikes B the latter becomes compressed, and almost instantly recovering its former figure, reacts on C, this undergoes a change in its turn, and reacts on D, &c., until the last ball, G, is acted on, which, having no one to oppose, obeys the force and separates from the rest, forming a determinate angle, GMH.

71. If a number of ivory balls, instead of being suspended, be placed on a table, so that their centres lie in the same right line; and one of them, A, being separated from the rest, be propelled towards *a* with a certain degree of force, the terminal ball, *g*, moves off with a corresponding degree of momentum (all opposing forces apart); and gains the situation G, the intermediate spheres being unaffected, except in the imperceptable manner just described.

72. When a body unopposed by friction, or resistance of

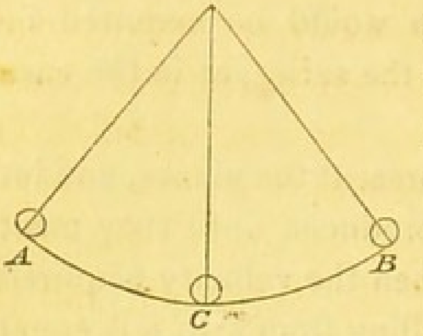
the air, descends a series of inclined planes, the velocity acquired by it is equal to that which would be acquired in falling through the vertical height of the series, as in the case of a single plane (62).



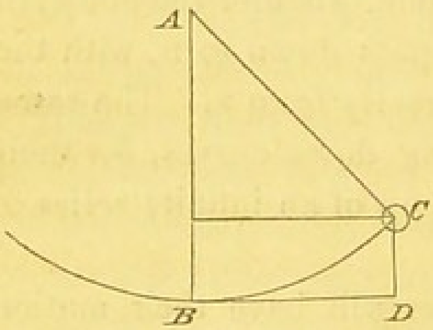
Let ABC represent the planes, and let C and B be produced until they meet AE in G, E, then the velocity acquired by a body falling from A to B is equal to that which it would acquire in falling from G to B, for the planes AB, GB have the same perpendicular height; and when this is the case with any two planes, the velocities acquired in falling down their whole lengths are equal (62). The body having reached B will descend BC with the same velocity, whether it fall down AB or GB; then the velocity acquired at C will be the same, whether the body fall down GBC or EC, and finally it will pass down to D, with the same velocity as if it had rolled directly from E. The same reasoning will apply to bodies falling down curves, for their figures may be considered, as made up of an infinite series of planes.

73. All bodies free from obstacles will have their motion as much accelerated, whilst descending; as it is retarded, whilst ascending a curve. Let CAB be a curve, and a ball be placed at C, the attraction of gravitation will cause it to descend to A; in this motion it will acquire a degree of momentum sufficient to carry it onwards to B, gravitation will once more pull it down to A, and the momentum thus generated will carry it onwards to C, again it will fall, and so on, oscillating from C to B, until opposing causes bring it to a state of rest. The whole time of ascent to B or C will be equal to the time of descent to A, as the velocities at equal altitudes are equal.

74. For the purpose of retaining the body in the curve (73) it may be fixed to a wire or string and then permitted to



oscillate; an instrument thus constructed is termed a *pendulum.* This, theoretically considered, consists of a ball suspended to a thread, unacted upon by any opposing or resisting forces. If the ball be raised to A and allowed to fall, it passes through C to B in the manner already described (73), the whole movement of the ball from A to B, or B to A, is termed *an oscillation;* from A to C, its movement is termed the descending, and from C to B its ascending *semi-oscillation.* The distance AB, measured in degrees, is termed the *amplitude* of an oscillation; and the *duration* of an oscillation is the time required to effect this movement from A to B, and vice versâ. The path described by the oscillation of a pendulum is the necessary consequence of gravitation, and explicable on the doctrine of resolution of forces (50); for let the pendulum AB be elevated to C, and then left free to move, it will be acted upon by the force of gravitation, and, describing the curve CB, reach B; this line may be considered as the resultant of two forces, one acting in the direction CD, and the other in the direction BD.



75. The duration of an oscillation is independent of its amplitude; and upon this depends the isochronous property of the pendulum; for the same time is required in a pendulum of given length to oscillate through 0·1° as through 10°, although the amplitude of oscillation in the latter is 100 times greater than that in the former. This fact depends upon the ball, in falling through 10 degrees, acquiring a considerable momentum, and, consequently, moving with greater velocity than if it had traversed a less number of degrees. The oscillations of the pendulum are, however, only isochronous when

the curve in which they move is a cycloid, a curve generated by the rotation of a wheel on a plane surface; the base of the cycloid being equal to the circumference of the circle whose rotation generated the curve, the area of which is always triple that of the generating circle.

76. The duration of oscillations does not depend upon the nature of the substance composing the pendulum, and is always in the ratio of the square roots of the lengths of the pendulum. Thus, if a pendulum of a given length perform one oscillation in a second, it requires one the square of that length to perform an oscillation in double, and the square root of the length to perform it in half that time.

The duration of an oscillation being as the whole numbers	1	2	3	4	5	6	7	8	9 &c.
The length of the pendulum will be as the squares	1	4	9	16	25	36	49	64	81 &c.

77. If a pendulum be made to vibrate in considerable arcs, a slight exception to the law of isochronism is observed, an addition of a minute portion of time being required to complete oscillations of a given amplitude, as compared to those of lesser arcs. If we take unity, for the time of an oscillation through an infinitely small arc, the excess of time required to complete larger oscillations will be

For an arc of 36°, 0·01675
15°, 0·00426
10°, 0·00190
5°, 0·00012
2°, 0·00003.

78. As the movements of the pendulum depend upon gravitation, and as this decreases as we recede from the earth's centre, this instrument affords a most valuable mode of determining the intensity of gravity, and, consequently, the distance from the centre, in different parts of the globe. This is done either by ascertaining the time required to com-

plete an oscillation of a standard pendulum; or, the length of a pendulum, requisite to complete an oscillation in a given time. The length of a pendulum required to vibrate seconds in the latitude of Greenwich is 39·1393 inches, and consequently one requiring two seconds to complete a vibration, will measure 156·5572 inches or rather more than 13 feet, whilst one vibrating but half seconds will measure but 9·784825 inches, or rather more than $9\frac{3}{4}$ inches.

79. The intensity of gravitation, (expressed by the number of feet, showing the velocity acquired by a dense body after falling for an entire second,) in any part of the world, is found by multiplying, by the length of the pendulum, the number, expressing the ratio of circumference to diameter, of a circle whose radius is 0·5; and dividing the product by the square of the duration of an oscillation. This calculation is better expressed thus

l = length of pendulum in inches;
t = time required for completing an oscillation in seconds;
π = the ratio of circumference to diameter or 3·1415927;
g = the intensity of gravitation as above explained:
then the formulæ for the pendulum will be

$$t = \pi\sqrt{\frac{l}{g}}, \text{ and consequently } g = \frac{\pi^2 l}{t^2}.$$

80. As an example of the use of the latter formula, let us suppose that the force of gravity, or velocity acquired by a body falling freely during one second of time in England, is required; then, by logarithms,

$$\begin{aligned} \log.\ \pi^2 &= 0{\cdot}99430 \\ \log.\ (l = 39{\cdot}1393) &= 1{\cdot}59261 \\ \hline & \quad 2{\cdot}58691 \end{aligned}$$

corresponding to 386·29 inches, or, more accurately, 386·2394, as before stated (56). Again, suppose the same question has to be determined with regard to Sierra Leone; at this place Major Sabine has determined the value of l, or length of pendulum beating seconds to be 39·01954 inches, consequently,

$$\log \pi^2 = 0\cdot99430$$
$$\log \; l = 1\cdot59128$$
$$\overline{2\cdot58558}$$

corresponding very nearly to 385·10 inches, which will be the velocity acquired by a body falling freely during one second, at Sierra Leone.

81. The following are the results of some measurements of the seconds' pendulum, at different parts of the world:

Place.	Latitude.	Value of l, or length of pendulum.	Observers.
Leith	55° 58′ 41″ N.	39·15540	Capt. Kater.
London	51° 31′ 08″ N.	39·13908	Do.
Ascension	7° 55′ 48″ S.	39·02406	Major Sabine.
Sierra Leone	8° 29′ 28″ N.	39·01954	Do.
Jamaica	17° 56′ 07″ N.	39·03508	Do.
Spitzbergen.........	79° 49′ 58″ N.	39·21464	Do.

By observations and calculations of this kind, the flattening of the earth at the poles, and bulging out at the equator, has been most accurately determined (43).

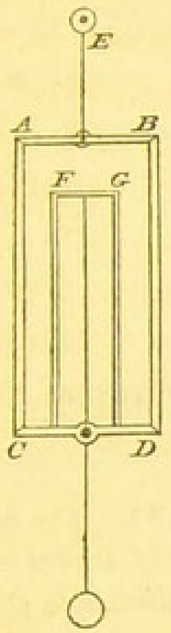
82. In the theoretical considerations and formulæ above mentioned, we have considered only the simple pendulum, or one whose wire is absolutely without weight, a condition of course physically impossible. Some slight reservation must, on this account, be made in applying to practice the formulæ of the pendulum. If a pendulum be suspended by means of a knife-edge, and unopposed by the resistance of the atmospheric air, it will continue oscillating for several hours, describing equal arcs in equal times, until it gradu-

ally comes to rest; as, however, the wire supporting the ball is never destitute of weight, there are some opposing causes to its completing an oscillation in a theoretically correct period, which must be noticed. If the pendulum AC be allowed to oscillate, and the wire be without weight, the duration of its oscillations will be consistent with theory; but as the wire is ponderable, every portion of it has a tendency to complete the oscillation in less time than the molecule beneath it, for if the pendulum be only as long as AB or AC, it will of course complete its vibrations in much less time than if as long as AD. Accordingly, every portion of wire will tend to complete its oscillations in different times, and these actions will, to a certain extent, oppose each other. At a certain point in the pendulum these actions will be mutually neutralized, and this is termed the *centre of oscillation*. This point can, practically, be brought very low into the ball of the pendulum; this is effected by making the ball very dense in comparison with the wire, to which it is attached. The *length* of a compound, or ordinary pendulum, is the distance from this centre to the point of suspension.

83. The centre of oscillation is the same with the centre of percussion, or that point where all the percutient force of a rod or bar is concentrated; this differs materially from the centre of gravity, for on striking anything with a stick at its middle point, it is well known that the whole force of the blow will be much less, than if the body be struck with that portion of the stick more remote from the hand.

84. As all bodies are acted upon by changes of temperature, so that their length becomes altered, it is of extreme importance to have a pendulum constructed, in such a manner as to be unaffected by such changes. Several modes have been proposed to effect so desirable an object, none, however, are more effectual than the well-known gridiron, or compensating pendulum, composed of two or more metals, so arranged that the expansion of the one

counterbalances that of the other. In the simplest form this consists of a parallelogram of steel, ABCD, fixed to the rod E, by which the whole pendulum is suspended; the copper rod FG, bent twice at right angles, is fixed by its lower ends to the transverse piece CD, from the upper part of FG, the rod supporting the ball of the pendulum is affixed. It is obvious, that as copper dilates much more than steel by equal elevations of temperature, in the proportion of 1·00191880 to 1·00118980; if the size of the steel and copper bar be properly adjusted, any elevation of temperature which, by expanding the steel bar, would increase the length of the pendulum, will be completely counteracted, by the expansion of the copper bar in the opposite direction. The importance of an arrangement of this kind is sufficiently obvious, as an alteration of 30° of temperature, by affecting the length of a pendulum, would introduce an error of 8 seconds in 24 hours. In all observations with pendulums requiring great accuracy, the lateral attraction of mountains and elevated buildings (27), as opposing the attraction of the earth, must be carefully borne in mind, otherwise errors of great importance will be introduced into our calculations.



CHAPTER V.

OF THE MECHANICAL POWERS, OR SIMPLE MACHINES.

85. The mechanical powers furnish the most simple instruments used for the purpose of raising or supporting weights, or communicating motion to bodies; and all the machines, complicated as they are, with which the ingenuity of man has furnished us, are nothing more than combinations of these simple powers. By means of these simple machines it must not be supposed that we beget or increase force; all that we do, is to apply force in a convenient and economic manner: thus, if a man could raise to a certain height 200 pounds weight in one minute, with the utmost exertion of his strength; no power could enable him to raise 2000 in the same space of time. If left to elevate the mass by his own unaided strength, he would be obliged to divide the mass into ten different portions, and raise each separately, whereas, by means of one of the simple machines, he will be enabled to raise the

entire mass at once, requiring, however, ten times the number of minutes in which he raised the 200 pounds.

86. Thus it is, *in limine*, obvious that we exchange time for power in using simple machines; and this is true with all the apparatus to which that term has been applied. The simple machines may be divided into three species:

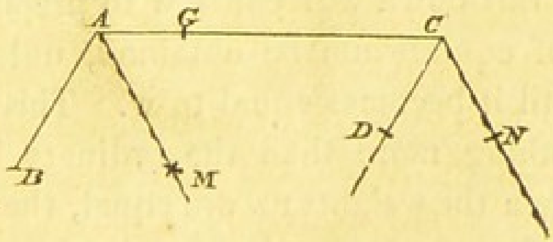
1, The lever,
2, The pulley,
3, The inclined plane,

the theoretical properties and peculiarities of which, with their chief modifications, we will now briefly describe.

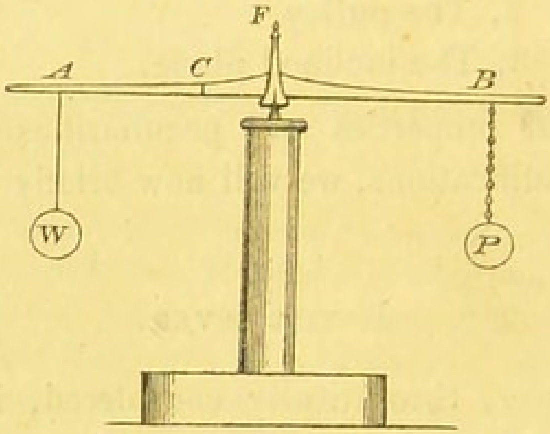
1. THE LEVER.

87. The lever, theoretically considered, is an inflexible rod, destitute of weight, perfectly straight, and moving without friction on a fulcrum or support, corresponding to the centre of motion.

Referring to what has been already stated with regard to the centre of parallel forces (31), we find that whenever a series of forces, perfectly parallel in direction, act upon a mass, they may be replaced by one force, which may be considered as their centre, or resultant. The following are the chief properties of this resultant. A. It is equal to the *sum* of the forces if they are all exerted in one direction, and to their difference if exerted in opposite directions. B. It is parallel to the forces of which it is the resultant. C. It is placed at a certain point G in such a manner that the distances GC, GA

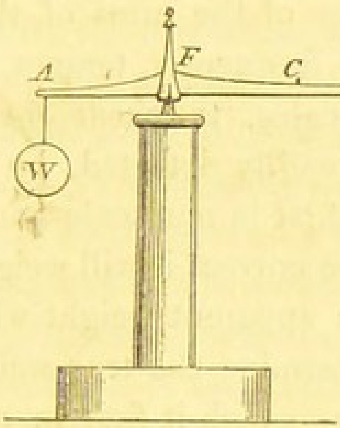


are in the inverse ratio of the forces CD and AB; and it is this point which is termed the *centre of parallel forces.* D. This point remains the same when the forces change their absolute directions, providing they remain parallel; for if the above forces act in the direction CN, AM, instead of CD, AB, the centre will still be G, because they have not changed their intensity, and their power is in the inverse ratio of GC, GA.



88. Let the bar AB be balanced on a fulcrum in its centre, it will, of course, remain in equilibrium: suspend from the end A a weight; immediately this mass is added, the centre of gravity will no longer be over the fulcrum but near the end A, and this power, being unsupported, will be drawn down by the attraction of the earth. Then suspend from the end B a similar weight P; the centre of gravity of the whole, as the bar and the weight may be considered as forming one mass, will be once more over the fulcrum, and the whole will be supported in equilibrio. If, instead of P being equal to W, it be one fourth less, then the centre of gravity will be no longer over the fulcrum, but nearer A, as at C, and the earth drawing this down will cause W to preponderate; nor can the state of equilibrium be obtained, unless weights be added to P, until it becomes equal to W. This form of lever is evidently nothing more than the ordinary balance; and we find that when the weights PW are equal, the length of the lever on both sides of F must be equal; these portions FA, FB are termed the arms of the lever.

89. If the weights PW remain equal, but the position of the fulcrum be changed to F, then equilibrium will no longer occur, for the arm FB will preponderate; this necessarily occurs, for the centre of gravity, C, being no longer supported,

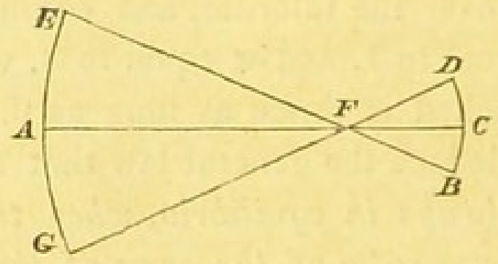


the force of gravitation draws it towards the earth. But let AB be graduated into four equal portions AF, FC, CE, EB, and let the point F be supported: it is obvious that things remaining as they were, a state of equilibrium can only be obtained by throwing the centre of gravity over the point of support, or fulcrum. This necessarily occurs by diminishing the weight P; and if this be done gradually, the centre of gravity will be found to approach F in proportion as we diminish P; and when this is equal to one third of W, the centre of gravity will be exactly over the fulcrum, and equilibrium obtained. Now, as P is equal to 1, and W equal to 3, whilst the arm to which P is attached is thrice as long as that to which W is suspended, we deduce the general law that *the power* P *and weight* W *are always in equilibrio, when they are to each other in the inverse ratio of the arms of the lever, to which they are attached.* Consequently, any weights will keep each other in equilibrio, on the arms of a straight lever, when the products arising from multiplying each weight by its distance from the fulcrum are equal on each side of the fulcrum; and, as in the above example, $P = 1$ and $W = 3$;

whilst AF = 1 and FB = 3, it follows that (W × AF) = (P × FB) and both being equal to 3, equilibrium necessarily results. Of the lever with unequal arms, the common steelyard, used for weighing heavy weights, is a good example.

90. As a smaller weight is made to counterbalance a greater, by lengthening one of the arms of the lever when arranged as a balance, it frequently tempts the dishonest vender to thus alter his scales, to cheat the unsuspicious buyer; of course this is readily detected, by weighing the substance to be purchased first in one scale-pan, and then in the other. If the balance be correct it will weigh the same in both; but if incorrect, its apparent weight will be different in each scale-pan. To determine the true weight of a substance with such a balance, weigh it first in one scale-pan, then in the other; multiply these two weights together, and take the square root of the product. Thus, if a substance weighed 253 pounds in one scale and 251 in the other, $\sqrt{251 \times 253} = 252$ pounds, the true weight.

91. In the lever, with unequal arms, we see that the velocity with which its extremities move is very different. Let the line AFC represent a lever, turning on the fulcrum F as on a centre, and suppose weights to be attached to the end C, and a force applied to A sufficient to move the weight,



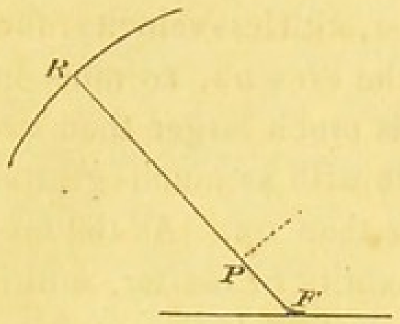
then, whilst the latter describes the arc DCB, the force applied will pass through the arc EG, the length of each arc being in the inverse ratio of the force applied to each, and in the direct ratio of the arms of the lever. We see also that a small weight attached to A and passing through the space

EAG, will, by its velocity, generate a degree of momentum sufficient to counterbalance a much heavier weight attached to C, moving, as the latter necessarily must, with less velocity; for, as from the conditions of this lever, the arcs DB, EG must be described in equal times, and as EG is much larger than DB, it is obvious that the end must move with as much greater velocity than C as the arc EG is larger than DB. As the momentum of a body is equal to its quantity of matter, multiplied by its velocity or quantity of motion (66); we learn that equilibrium must occur in a lever, when the weights at either end, multiplied by the velocities with which they move, are equal to each other. From this reasoning, we also become convinced of the truth of the statement we set out with, that the application of the mechanical powers is an exchange of time for power.

92. These levers have been termed levers of the first class, and are characterized by having the fulcrum at some point between the power applied and the resistance to be overcome. Those levers in which the fulcrum is applied at one end, and the resistance at an intermediate point, have been termed levers of the second class; whilst those in which the power is applied between the fulcrum and resistance are placed in a third class. The only real distinction that it is necessary to make, is between levers in which the fulcrum is between the force applied and the resistance, and those in which the fulcrum is at one end. The proportion between the forces to produce equilibrium is expressed in the same terms in each case, the great difference between them being that when the fulcrum is central, as in the lever already adverted to, the pressure upon it is equal to the sum of the forces applied, and to their difference, when the fulcrum is terminal.

93. That modification of the lever in which the force is applied between the fulcrum and resistance, is not very frequently met with; indeed, on account of the mechanical disadvantage in which the force is necessarily exerted, it is

never used except to gain considerable velocity; for, if RPF represent such a lever moving on a hinge as a fulcrum at F, and force be applied at P, it is obvious that whilst P moves through a small arc, R will describe a very large one; and as both are performed in equal times, the velocity of the end R is enormously greater than the end near F. The common tongs, used to supply the fire with fuel, afford an example of this kind of lever; the sheep-shears, sugar-tongs, &c. are similar examples.



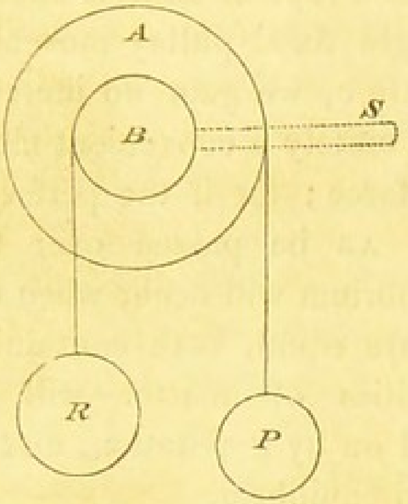
94. Of the first described lever, in which the fulcrum is central, examples are met with in scissors, forceps, pincers; and in the ordinary poker, when it rests on the bar, in the act of stirring the fire, &c. Of the other kind of the lever, in which the fulcrum and power applied are both terminal, an oar will afford an example, the water being the fulcrum, the boat is the resistance, and the hand of the rower is the power. The chipping-knife used by druggists, in which the end is fixed to a board, and the chaff-cutter, are also instances of this kind of lever.

95. As a general statement of the necessary conditions for obtaining equilibrium with the lever, the following formula, in which $R =$ resistance to be moved, $P =$ power applied, $p =$ the arm to which P is affixed, and $r =$ that connected with R, may be useful.

$$P : R :: r : p, \quad \text{and} \quad P \times p = R \times r.$$

Simple levers are sometimes so combined, that instead of acting directly on the resistance, they act on a second lever, and this sometimes on a third, which then exerts their combined effect upon the resistance. Some varieties of cutting bone-forceps are constructed in this manner. The patent weighing-machine is a combination of levers, arranged at right angles to each other.

96. The wheel and axle is a modification of the lever, in which considerable mechanical convenience is gained; this machine consists of a cylinder B, termed the axle, turning on a centre, and connected with a larger circle of wood or other substance, A, called the wheel; sometimes this is replaced by a spoke, as S, fixed into B, to the end of which the force is applied; the resistance to be overcome is connected with a rope wound round the small cylinder B, whilst the power is applied to the circumference of A, generally by means of a rope P, acting in the direction of a tangent to A. Here the radius of the smaller circle or axle may be considered as corresponding to the short arm, and the radius of the larger, or wheel, or length of the spoke fixed into A, as the longer arm of a straight lever; and accordingly we find that equilibrium is obtained when the power applied is to the resistance to be overcome in the same ratio as the radius of the smaller cylinder, or axle, is to that of the larger, or wheel; and calling the radius of the wheel W, and that of the axle w



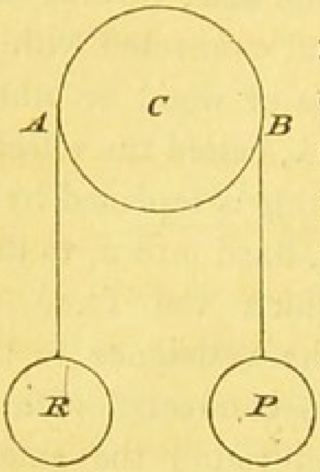
$$P \times W = R \times w.$$

The winch, windlass, capstan, crane, afford examples of the practical application of this useful modification of lever.

2. PULLEY.

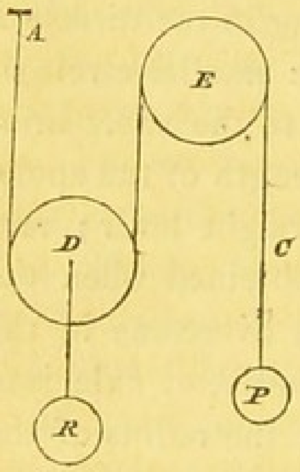
97. The simplest form of pulley consists merely of a ring, or groove in a beam, used of course only to change the

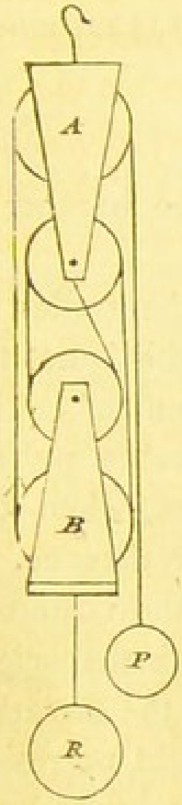
direction of motion: as usually constructed, it is a small wheel moveable about its centre, in the circumference of which a groove is formed, to admit a rope or flexible chain.



In the single fixed pulley moveable round its centre C, we gain no increase of power, but merely a convenient mode of applying force; for if the perfectly flexible rope AB be passed over the pulley, equilibrium will occur when the weights RP are equal, both containing equal quantities of matter will be equally acted on by gravitation, and be necessarily in equilibrio.

98. If we use a moveable pulley we become enabled to raise a resistance of 2 by a power of 1; let the rope AC be fastened to a solid beam at A, and passed under the groove of a moveable pulley D, be brought over a fixed pulley E; the only use of which is to render the application of force more convenient. Let a weight R be suspended from the moveable pulley D, and a force or power, P, applied at the end C: R will obviously be supported equally by the power P and the beam A, which reacting against the power applied, aids in keeping the weight elevated in the same ratio as P does, action and reaction being equal and contrary (45), and accordingly R will be supported by a force P, equal to one half its weight. Hence in the single moveable pulley, equilibrium is obtained when the power is to the resistance as 1 to 2. In the pulley, as in the lever, time is lost as power is gained, for a little reflection will show, that for R to be raised one inch, P must fall through two inches, as the end A is immoveable.



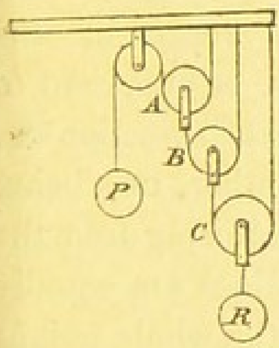


99. Sometimes a pulley is compound, consisting of two portions termed blocks, AB, each containing two or more pulleys; in such an arrangement, each fold of string sustains a share of the weight, or resistance, and equilibrium will result when

P : R :: 1 : number of strings on the lower block.

And in the pulley figured in the margin, the folds of string in the lower block being 4, a power of 1 will sustain a resistance of 4.

100. Instead of the string folded on the pulley being entire, it is sometimes divided into several portions, each pulley hanging by a separate string, one end of which is attached to a fixed beam; here we gain a great increase of power, attended by a corresponding loss of time, as the power P must move much faster than R, and acquire considerable momentum, which, indeed, becomes active in enabling it to put R in motion. In such a system, the gain of power may be determined by calculating that power of 2, whose index is the number of moveable pulleys.



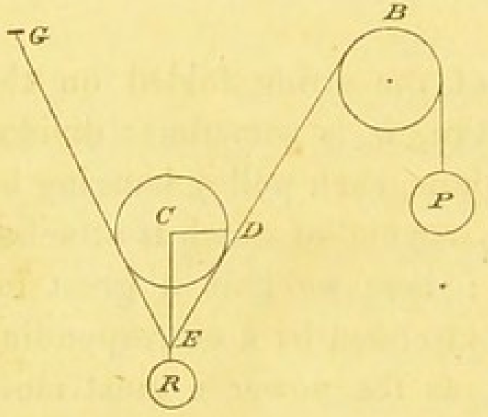
$$P : R :: 1 : 2^n.$$

In the system of pulleys, figured in the margin, there are three moveable pulleys; now the third power of 2 is 8, and accordingly, with such an arrangement, we can, with a power of 1, counterbalance a resistance of 8. The fixed pulley in this system does not increase power, but merely affords a more convenient mode of applying force. When the pulleys are connected each to a separate string, the ends of the latter being attached, not to a beam, as in the last case, but to the resistance to be overcome, some mechanical loss is sustained, and equilibrium is obtained, when

$$P : R :: 1 : 2^n - 1$$

2^n being that power of two, whose index is the number of moveable pulleys.

101. In the preceding cases, the strings of the pulley or their folds are supposed to be parallel; when this is not the case, some alteration takes place in the conditions of equilibrium. Taking the case of the single moveable pulley,



equilibrium occurs, when the power is to the resistance, as radius to twice the cosine of the angle, in which the weight acts. Let CR be the direction in which the weight or resistance R acts, produce BD until it meets CR at E; then, if DE be taken to represent the power at P; it may, by the resolution of forces, be supposed to be the resultant of two forces, one acting in the direction CE, and effective in raising the weight R, the other, CD, being counteracted by an equal and opposite force arising from the tension of the string EG; and as the two strings are equally active in sustaining R, 2 CE will represent the whole weight sustained, and

$$P : R :: DE : 2\ CE :: \text{rad} : 2 \cos DEC.$$

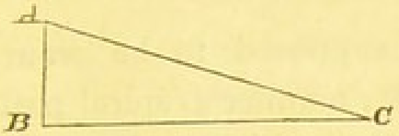
When the strings become parallel, the angle DEC vanishes, and its cosine becomes radius, then P : R :: 1 : 2, as already explained (98).

102. The pulley has been referred, with great justice, to the lever, of which indeed it may be considered as a modification; the radii of the pulley representing the arms of a lever, on which, by means of the string, the power is made to act.

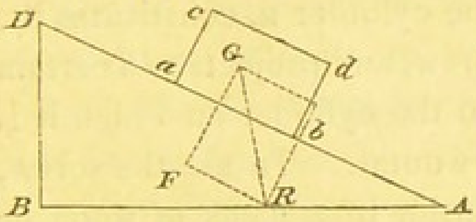
3. INCLINED PLANE.

103. The action of this mechanical power depends upon the simple principle, that a body free to move can be supported only by a force equal to its own weight, unless it can deposit a portion of this weight on a fixed obstacle, in which case it can obviously be supported by a smaller force.

An inclined plane consists of any substance sufficiently hard inclined at a certain angle: in every plane three parts



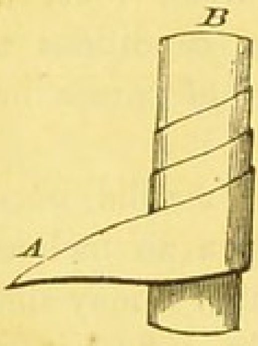
are distinguished, its height AB, its length AC, and base BC. In our theoretical considerations of its action, its surface must be considered as absolutely hard and smooth, conditions to which the best constructed instruments afford of course but distant approximations.

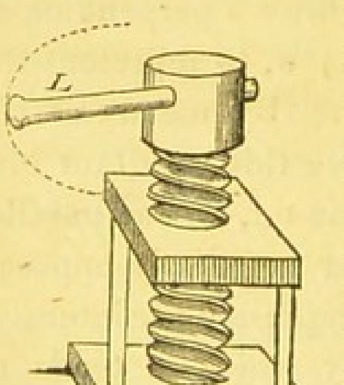


104. Suppose a solid, *abcd*, to be placed upon an inclined plane, ABD, so that it may slide down under the influence of gravitation; to calculate the force required to retain it on the plane, draw a perpendicular line, GR, from the centre of gravity (31) G, to represent the direction of the earth's attraction for it. By means of the parallelogram of forces (50), decompose this resultant into two forces GF, perpendicular to the plane DA, and G*b* parallel to it. It is seen at once that the force GF is entirely opposed by the surface of the plane, and G*b* will represent the intensity of force acting on the body *abcd*, by which it tends to be drawn down the plane; consequently, the force necessary to retain the body on the plane will be to the total weight of the body as the line G*b* is to the diagonal GR, or what comes to the same thing, as the height of the plane is to its length, because the triangle G*b*R = triangle DBD; and using the letters referring to the last figure, equilibrium will be obtained

on the inclined plane, when P : R :: DB : DA ; therefore the less the height of the plane, the greater the weight that can be sustained on it by a given power. Here, as in the other mechanical powers, velocity is lost as power is gained, for as the vertical height to which the body is raised by means of the inclined plane is equal only to the height of the plane, or sine of the angle of inclination ; and, as in the preceding figure DA is considerably larger than DB, it will, supposing the weight raised to pass over equal spaces in equal times, necessarily require a longer time to move it through the length DA than DB.

105. If an inclined plane be supposed to be wound spirally around a cylinder, in a similar manner as spiral paths are carried round mountains to lessen the steepness of ascent, we have a *screw*, one of the most useful modifications of a simple machine. The edge of the inclined plane A, wound round the cylinder B, constitutes the *thread* of the screw, and projects to a certain distance beyond the cylinder on which it is supposed to be wound. To use the screw, a hollow spiral is carved in the inside of a block of wood or metal, termed the female screw; this hollow spiral must be of such a size as to admit the projecting thread of the first, or male screw. Thus constructed, the male screw is generally turned by means of a lever, and fixed into its head, thus, indeed, forming a compound machine, the power of the lever being added to that of the simple screw. The power of the screw increases with the circumference of the circle described by the lever L, to which the power is applied, and with the diminution of the distance between two contiguous threads of the screw, measured in a direction parallel to the axis. Calling this distance D, and

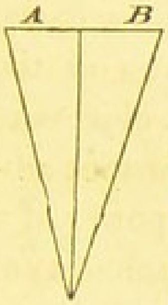




ference of the circle described by the lever L, equilibrium will be obtained, when

P : R : : D : L.

106. When two inclined planes are placed with their bases approximated, as AB, we have a wedge,



which is a triangular prism; contained by plane figures, of which two that are opposite are equal, similar, and parallel, the others being parallelograms.* This is occasionally used as a mechanical power to lift heavy weights to small elevations, but is more generally used for the purpose of cleaving timber; the edge being introduced into a cleft made to receive it, and the wedge forced in by repeated blows of a hammer upon its back. The great advantage of the wedge appears really to depend upon the percussion used to urge it into the mass of timber, &c. exciting vibration between the particles of the solid, and thus permitting the edge to introduce itself between them; certainly the direct action of a weight pressing upon the back of the wedge can bear no comparison with the immensely greater effect gained by percussion.

107. Theoretically speaking, it has been supposed that the power gained by the wedge bears the same proportion to the resistance to be overcome, as half its back does to its height; and thus, that a weight of 60 may be raised by a force of 20, providing we use a wedge, the half of whose back shall bear such a proportion to its length as 20 does to 60, or 1 to 3. The only part of this theory which is really supported by practical observation is the fact, that the power of the wedge increases, as its width or back diminishes. Many of our domestic instruments are modifications of wedges: a saw is composed of a series of them, as are knives,

* Euclid, B. xi. Def. 13.

scissors, razors, &c. which are nothing more than fine saws. Needles, pins, &c. may be considered as acute wedges.

108. In this outline of the properties of the mechanical powers, or simple machines, one important source of resistance to their action has been omitted; because the consideration of it, as applied to their theory, is rather a branch of practical mechanics, than of the elementary portions of physical science. Friction, the rigidity of cordage, and the inertia of the several parts of the machine itself, are important objects of study to the mechanic, as they oppose very important obstacles to the development of the full mechanical power of a machine, and prevent his obtaining such an amount of power as theoretical reasoning would lead him to anticipate.

109. In that elaborate and wonderful part of the animal economy, the muscular system, we have much to admire and wonder at, in the adaptation of power, to move the bony levers constituting the skeleton; here, where great power, rapidity of movement, and elegance of figure, are equally attended to, we find evidence of infinite wisdom in the adaptation of mechanical power, apparently the least advantageous, to the most important motor functions of the body. In considering the mode in which *extension* of the limbs, especially of the upper extremities, is performed, we see a set of levers of the first kind; or those in which the power and resistance are at opposite ends, and the fulcrum intermediate, called into action. In the *flexion* of the limbs, we have a set of beautiful examples of levers of the third, or that kind, in which the resistance and fulcrum are terminal, and the power intermediate. And in certain other muscular efforts, as raising the body on tiptoe, and depressing the lower jaw, we have examples of levers of the second denomination, in which the resistance is intermediate between the fulcrum and power.

110. Although the insertion of the flexor muscles, causing the limbs to act as levers of the most disadvantageous kind, might appear, at a superficial glance, to render the action

of the limbs less energetic; a moment's reflection will show that by the insertion of muscle near the fulcrum, we gain an immense increase of velocity at the other extremity of the lever (93), generating a degree of momentum infinitely more fitted for the purposes required by the movements of the limbs than if, by their insertion further from the fulcrum, they had been so placed as to exert their power to the greatest mechanical advantage. For this, at first sight, apparent advantage would have permitted us to use our now agile limbs with extreme slowness, with the additional disadvantage of unsightliness.

111. The following are some among many examples of levers in the human body:

A. *Fulcrum between the Power and Resistance.*

POWER.	FULCRUM.	RESISTANCE.
Triceps extensor cubiti and anconæus.	Condyles of humerus.	Arm and hand, with any weight attached to them.
Muscles arising from tuberosities of ischia, and inserted into the lower extremities.	Heads of femora.	Weight of the trunk, when flexed upon the thighs.

B. *Fulcrum terminal, Resistance intermediate.*

Muscles connected with tendo achillis.	The floor pressed by the toes.	Weight of the trunk pressing on ankle-joint.
Digastricus, and other depressors of the lower jaw.	Articulation of the lower jaw.	Action of the temporal and masseter muscles.

C. *Fulcrum terminal, Power intermediate.*

Biceps flexor cubiti and brachialis.	Condyles of humerus.	Weight of arm and hand.
Deltoid.	Glenoid cavity of scapulæ.	Weight of the arm.

112. Of compound pulleys we should scarcely expect, when all is characterized by beautiful simplicity, to find any exam-

ples; of simple pulleys, merely to alter the direction of motion (97), we have a few instances. The structure of the pulley-like organ is always extremely simple, usually being merely a groove in the bone covered with cartilage, sometimes a bony hook, and in another case a tendinous ring. The tendon of the obturator internus, in passing out of the pelvis, glides in a groove in the ischium, so as to alter its direction, affords an example of the first and simplest pulley in the human body; the hook-like process through which the tendon of the circumflexus palati glides, so as to alter its direction to a right angle, illustrates the second form of pulley; and of the third, or tendinous ring, we have an example in the ring in the depression in the frontal bone, through which the tendon of the obliquus superior muscle of the eye glides, becoming thereby bent to an acute angle.

113. Of the inclined plane or its modifications, we have no instance in the skeleton; the sacrum is certainly not an example of the wedge, notwithstanding its figure. The only approach to a wedge in animal structure which I am acquainted with, is that bony apparatus discovered, by Sir Philip Egerton, in the neck of the ichthyosaurus, an extinct antediluvian reptile; three wedge-like bones have been described by him as connected with the cervical vertebræ, fitting into spaces between them; these wedges are supposed to have been withdrawn when the animal flexed the head upon the trunk, and to be introduced between the vertebræ when the head was raised; so as to prevent that vast muscular effort which would otherwise be required, to keep the enormous and disproportionate heads, of these animals extended.

NOTE.

On the subjects treated of, in the preceding five chapters, the student may consult, with advantage, Sir David Brewster's edition of Ferguson's Mechanics, and Dr. Olinthus Gregory's Mechanics, as well as the monographs in Sir David Brewster's Encyclopædia, Dr. Lardner's Cabinet Cyclopædia, and the Cyclopædia Metropolitana. Among continental authors, the works of Poisson, Pouillet, Biot, Hauy, Quetelet, &c. should be carefully studied.

In the Essays on Mechanics, by the late Dr. Wood, of Cambridge, and Professor Whewell, the reader will find the laws of statics and dynamics mathematically treated. The propositions in the Principia of Newton, bearing on these subjects, will of course be studied with attention by all who desire an intimate acquaintance with them, whilst those who content themselves with a more general knowledge of these subjects, would do well to consult Euler's Letters to the Princess of Anhalt-Dessau. To facilitate the study of these works, the following references to the portions bearing on the contents of the preceding chapters may be useful to the student:

Chap. 1.—Newton, bk. i, def. 1, 3; bk. iii, rule 3; Euler, vol. 1, letters 1, 69, 74, and vol. 2, let. 7, 12.

Chap. 2.—Newton, bk. i, def. 5, 6, 7; bk. iii, prop. 1, 7, 9; Euler, vol. 1, let. 45, 58, 62, 68.

Chap. 3.—Newton, bk. i, cor. 1, 2, def. 8; bk. iii, prop. 19; Euler, vol. 1, let. 3, 71.

Chap. 4.—Newton, bk. i, cor. 6, prop. 50-55, sect. 7; bk. ii, prop. 40, sect. 1-3, 6; bk. 3, prop. 19, 20, 24; Euler, vol. 1, let. 45-68.

Chap. 5.—Newton, bk. i, cor. 6, scholium.

CHAPTER VI.

GENERAL PROPERTIES OF FLUIDS AT REST. (HYDROSTATICS.)

Properties of Fluids, 114. *Elasticity of,* 115. *Compressibility of Water,* 116. *Equality of Pressure,* 117, 118—*Level surface of,* 119. *Level of the Sea,* 120. *Downward Pressure,* 121. *Upward Pressure,* 124. *Lateral Pressure,* 126, 7. *Centre of Pressure,* 128. *Communicating Vessels,* 129, 130. *Equilibrium of Solids in Fluids,* 131. *Principle of Archimedes,* 132. *Specific Gravity of Solids,* 133-136—*of Liquids,* 137—*of Gases,* 139. *Aerometer,* 138. *Table of Specific Gravity.*

114. Fluids, or liquids, are characterized by the extreme mobility of their molecules on each other, by which they are prevented having any distinct form like solids, always assuming that of the vessel containing them. Fluids obey all the laws which have been explained in the preceding chapter, with such modifications as depend upon their molecular constitution; they obey most strictly the attraction of gravitation, (25), and are capable of assuming motion, in the same manner as solids, in cases where the ready mobility of their particles on each other does not interfere. A mass of water, or other fluid, in falling from a given height, would produce effects as important as an equal mass of any solid, if no opposing causes existed; and the reason why no one would fear the falling of a pailful of water on his head from an elevation, capable of giving to the pail itself a degree of momentum sufficient to fracture his skull: is that, in falling, the water is opposed by the air, and, from the ready manner in which its particles allow of separation, it becomes divided into a kind of irregular shower, producing no effects likely to be dreaded

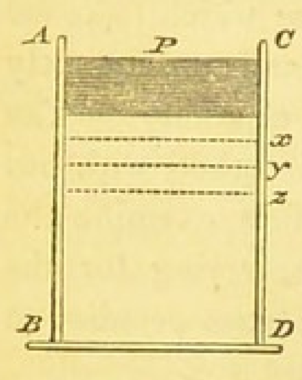
from their mechanical violence. If the particles of water were tied together by increased attraction of aggregation, as by freezing, then its mechanical effects would be as serious as those of a mass of stone.

115. Fluids have been divided into elastic and non-elastic: a distinction by no means well founded, for it is quite impossible to draw a distinct line of demarcation between those fluids which, as water and alcohol, are but slightly compressible, and therefore but slightly elastic; and those which, like air and all gases, admit of ready compressibility, and consequently are endowed with a considerable share of elasticity. The properties of the one class are common to the other, with but slight modifications. We shall therefore first examine the physical characters of fluids *generally*, reserving for the ensuing chapter a consideration of the properties peculiar to the eminently elastic fluids, or gases.

116. Liquids, properly so called, of which water may be taken as the type, are but slightly compressible; this character indeed was for some time doubted, as the celebrated experiment, performed by the Florentine academicians, of inclosing water in an hermetically-sealed ball of gold, and causing the fluid to percolate the pores of the metal by pressure, was for a long time considered conclusive on this point, although all that it really proved was the porosity of the metal. From the experiments of Canton, the compressibility of water under the pressure of our atmosphere, equal to fifteen pounds on each square inch, was estimated at 0·000044; whilst Mr. Perkins has lately estimated the compression under the same pressure at 0·000048; and Professor Oersted, by means of an extremely accurate set of experiments, has fixed on 0·000046 as the degree of compression experienced by a given bulk of water, for each additional pressure of our atmosphere. The compressibility of liquids is also proved by the faint elasticity they really possess, shown by the copious scattering of drops in all directions, when water, or any other liquid, is poured from a height on a smooth surface. A vessel filled with a

liquid gravitates, in common with its contents, towards the earth; the fluid gravitating also independently of it, as, on piercing a hole in the containing vessel, it escapes towards the earth.

117. Liquids, on account of their extreme mobility, are capable of communicating pressure exercised on them equally in every direction, forming one of the most interesting characteristics of this class of bodies. To understand this curious



property, let ABCD be a vessel containing a liquid destitute of weight, and therefore theoretically unacted upon by the attraction of the earth, and let P be a solid piston, also destitute of gravity and exactly covering its surface. Now, as P is without weight, it does not press upon the fluid, and the sides of the vessel may be pierced without its escaping; but if we place on P a weight of 100 pounds, it will attempt to descend, and would reach the bottom of the vessel were it not opposed by the water; accordingly, the upper layer of fluid x becomes pressed by the piston, and would fall, if not supported by the subjacent stratum y, which thus in its turn becomes pressed; this acts on the layer z, and this on the subjacent layers transmitting the pressure exerted by the weight with which the piston is loaded to the bottom of the vessel. And as the whole surface of the base BD supports the pressure of 100 pounds, it follows that one half the surface supports but 50, and ·01 the surface but one pound, &c. From these considerations we may safely infer that,

A. Pressure is transmitted by fluids from above to below, upon horizontal surfaces, without becoming diminished.

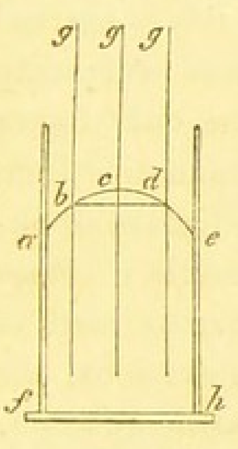
B. It is equal in every portion of the fluid.

C. It is proportioned to the area of the surface pressed.

118. The same phenomena will be observed at the sides of the vessel, for if any portion of it be perforated, the liquid rushes out, providing the weight still continues to act upon

the piston; and if a portion of one of the sides of the vessel be cut out, equal to the area of the piston, the force required to be applied to keep the fluid in the vessels would be found to equal that pressing on the piston, or 100 pounds. Finally, if a perforation be made in P itself, the pressure still continuing, the liquid rushes from below, and escapes in a jet d'eau, proving satisfactorily that *liquids transmit forces acting upon them, equally in all directions.*

119. Liquids can never attain a perfect state of rest, and be in a state of complete equilibrium, unless the particles in the upper and exposed layer form a surface perpendicular to the forces acting upon it; and every molecule of the mass of fluid experiences equal and contrary pressures. To render the first condition intelligible, let *aefh* be a vessel full of water, or other fluid; to attain a perfect equilibrium, the surface of the fluid must be in a plane perpendicular to the forces *ggg*, representing the directions of the earth's attraction. If, instead of forming a level surface, the fluid be supposed to describe a curve, *abcde*, a small horizontal layer, as *bd*, will be pressed by the weight of the molecules above it; this pressure will become transmitted laterally (126), and the molecules of fluid at *b* will be acted upon by this lateral pressure, and pushed outwards, because there is nothing to oppose this action; immediately other particles take their place, and being acted upon in a similar manner, become pushed out in their turn; and this effect continues until all that portion of fluid standing above the horizontal line *bd* becomes drawn down to form one level surface, and then the curve *bcd* vanishes, and an horizontal surface, *ae*, perpendicular to the forces *ggg*, is produced. The fluid will then be in equilibrio, providing the second condition obtains, that every molecule in the interior of the mass of fluid experiences equal and contrary pressures. That this is the case is evident, for every particle of fluid receiving the

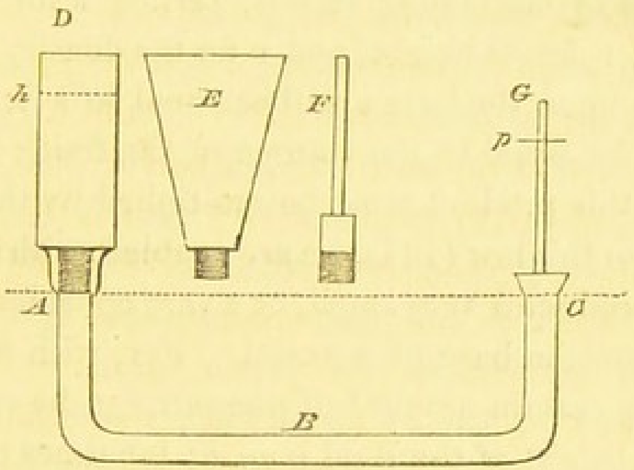


pressure of those above it tends, in consequence of the equality of pressure (117), to transmit it on every side; and if the pressure on two sides of the particles be unequal, it will be acted upon by the strongest force, and continue to move until it has attained a situation where all the forces acting upon it become equal. The only exception to the law of the level surface of liquids arises from the capillary attraction, or repulsion, exerted by the sides of the vessel (16-23).

120. We have a beautiful example of the truth of the law of equilibrium of fluids (119) in the figure of the surface of oceans and seas in a calm state, by which the cause of their superficial curvature becomes immediately apparent. We know that, in common with everything belonging to our globe, the seas obey the force of gravitation; and as this is exerted from the centre of the earth, the oceans and seas necessarily assume the spherical form, because this is the only figure whose surface is perpendicular to all the radii emanating from its centre. On this account, where a standard place of observation is required for very accurate barometric or other experiments, so as to enable observers in different parts of the world to compare the results of their observations, the level of the sea, or a given distance above it, is always chosen. The only considerable exception to the perfectly circular outline of the seas and oceans, arises from the centrifugal force generated by the rapid rotation of the earth (43). Among minor causes affecting the regular curve surface of the great mass of waters on our globe, may be mentioned those, which arise from certain physical features of the earth itself; the mountainous elevations on its surface attracting, by lateral gravitation (27), the water of seas and oceans towards them. If the mountains of the Cordilleras were about 100 times higher than they are, the seas would, by their attraction, be elevated into liquid mountains on both sides of the coasts of America, and the ports of France and Japan be left dry. The peculiar direction of winds and currents are sources of disturbance to an important extent, causing elevations in

particular and isolated masses of water: thus the level of the Red Sea at high water is more than thirty-two feet higher than the Mediterranean. The level of the Pacific at Callao is more elevated than the ocean at Carthagena by twenty-three feet; whilst the ocean at Dunkirk and the Mediterranean at Barcelona are at the same elevation.*

121. The pressure of a fluid on the bottom of the containing vessel is altogether independent of its shape, *and is equal to the weight of a column of fluid whose base is equal to that of the vessel, and whose height is the same as that of the contained fluid.*



The best mode of proving this statement is by means of the apparatus contrived by M. Haldat,† consisting of a bent glass tube, ABC, having at A a collar cemented, into which vessels of different shapes, DEF, can be screwed. The tube ABC is filled with mercury up to the dotted line, and the tube G fixed into C. The vessel D is then screwed on A, and water poured in as far as *h*, the base of the column of water will of course be equal in area to that of the surface of the mercury in the tube A. The mercury will then rise to a certain height in G, as *p*, in consequence of the pressure of the water in D on the surface of the mercury in A; then unscrew D and fix on the vessel E, and pour in water until it has attained the same vertical height as in D; on examining the mercury in G, it will be found at the same point P as when the cylinder D

* Pouillet, Physique, p. 115. † Ibid. p. 107.

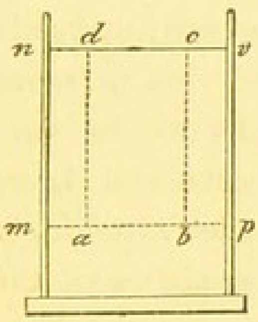
was fixed on A. Remove E and replace it by F, and on pouring in water to the same height, the mercury in G will attain the same elevation as before. Proving satisfactorily that the pressure exerted by masses of fluid is quite independent of their quantity; for the pressure was the same when either of the differently sized vessels D, E, F, were used; and varies solely with the vertical height, and area of the base, of the column of fluid. In the case of the funnel-shaped vessel E, the inclined sides support part of the weight of the fluid.

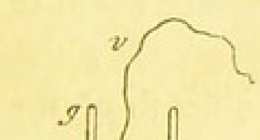
122. As a general formula for calculating the fluid pressure on the bases of containing vessels, setting B for the base of the column, H for its height, and D for the density of the fluid: the pressure upon the base B will be equal to $B \times H \times D$, for $B \times H$ will be equal to the volume of the fluid; and to have the weight, this product must be multiplied by the density D.

123. From this law (121), we are enabled, with a given bulk of fluid to produce a very small, or a very considerable amount of pressure on the base of a vessel. For, with a quantity of fluid $= F$, a certain amount of pressure can be exerted when the vertical height of the fluid is $= h$; ten times that pressure can be produced by narrowing the capacity of the vessel so that the vertical height of the fluid may be $= 10\ h$, and conversely the pressure may be lessened to $\frac{1}{10}$ by so inclining the sides of the vessel that the vertical height of the fluid may be only $= \frac{h}{10}$. By availing ourselves of this law, a cask may be readily burst by means of hydrostatic pressure; for this purpose let a cask be filled with water, and a tube about twenty feet in length be cemented into the bunghole. On pouring water into the vessel, pressure is exerted, equal to the area of the vessel multiplied by the height of the column of water in the pipe, and a degree of force sufficient to burst the cask with violence is generated. The well-known philosophic toy, called the hydrostatic bellows, illustrates the same fact: this consists of two circular boards connected loosely by strong leather; into the upper board is fixed a long glass tube, and on pouring water into the latter the boards become

separated, even when previously pressed together by a considerable weight. In this manner, when the space between the boards is nearly filled with water, and a man stands on the upper board, an ounce of water poured into the pipe will exert sufficient force to elevate him a few inches, notwithstanding the considerable weight the fluid pressure has to overcome.

124. In accordance with the foregoing observations, fluids exerting pressure in all directions, every layer of fluid presses as powerfully upon every superposed stratum, as it does upon all subjacent ones. Thus it is evident that all the particles composing any particular stratum of fluid, as *mp*, must be pressed upon by all above them, in the same manner as if they supported a solid piston equal to the fluid mass *nvmp*. If then we regard a portion only of the layer *mp* as *ab*, we can readily understand that this is at once pressed from above downwards by the column *dcab*, and from below upwards by an exactly equal force, in such a manner that, if a solid cylinder were immersed in the fluid with its base resting on *ab*, the upward pressure would tend to throw it out of the fluid. These theoretical considerations may be readily verified by means of an apparatus consisting of a stout glass tube, *g*, having a plate of brass, B, pressed against its base, and retained *in situ* by the string *v*; on immersing the whole in a vessel filled with water to *nn*, the plate will be pressed against the mouth of the tube by the upward pressure of the fluid. If water be then poured into *g* until it nearly reaches the external level *nn*, the plate will obey the attraction of gravitation and fall to the bottom of the vessel.

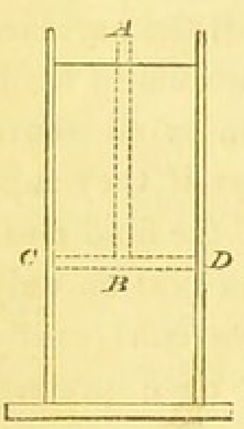




125. On account of this upward pressure of fluids, if a hole be made in the bottom of a ship the water rushes in, to oppose which, a force must be applied, equal to the weight

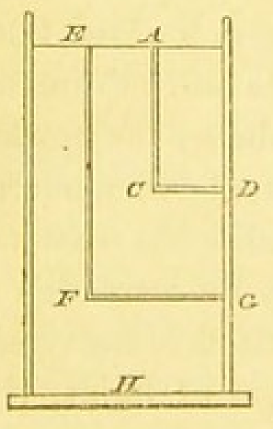
of a column of water, whose base is of the same area as that of the aperture in the vessel, and whose length is equal to the depth of the hole from the surface of the water. Hence, in vessels of large draught, the keels should possess considerable strength to enable them to oppose the upward pressure, exerted by the water in which they float.

126. As a consequence of the law of equal pressure, every portion of the sides of a containing vessel are exposed to pressure, corresponding to the weight of the fluid pressing against it. In the vessel of water, ACD, if a particle of fluid



situated at B be pressed by the column of water above AB, it will, for reasons already stated, be at the same time pressed upwards (124) by an equal force, and this pressure will be communicated laterally to the particles lying on the same horizontal layer between BC and BD: thus every point in the sides of the vessel is pressed with the same force, as the fluid particles contained in the horizontal layer corresponding to it are. As a general rule, the pressure supported by the sides of a containing vessel is equal to the weight of a fluid column, having for its vertical height the depth of the centre of gravity of the side below the surface; and for its base, a surface equal to that of the side of the vessel.

127. The lateral pressure increases with the depth of the fluid; for in the vessel H the fluid column

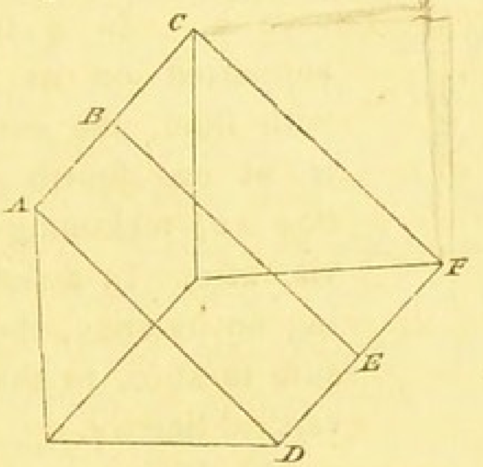


AC transmits its pressure (126) to the horizontal layer CD to D; and the column EF pressing upon the layer FG, has its force transmitted by FG to G; then the pressure at G must be greater than at D, because EF is longer than AC. Therefore the formula already given for calculating the pressure on the base (122) will apply to the lateral pressure; letting B represent the side instead of the base of the vessel.

In a vessel of water of 5 feet deep, the pressure on a square inch of lateral surface, at 1 foot deep, will be = $\frac{1}{2}$ pound.

2	......	= 1	..
3	......	= $1\frac{1}{2}$	..
4	......	= 2	..
5	......	= $2\frac{1}{2}$	..

When the pressure upon the base of a cubical vessel of water is known, the lateral pressure can be readily calculated, for the pressure upon any one side of a cubical vessel, filled with fluid, is one half of the pressure on the base. For the bottom sustains a pressure equal to the whole weight of the



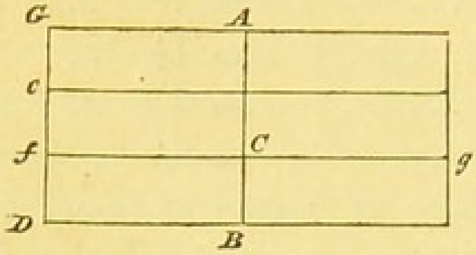
fluid, and the pressure sustained by the side is equal to the weight of the prism ABCDEF, which is half the cube,* and therefore equal to half the pressure on the base.

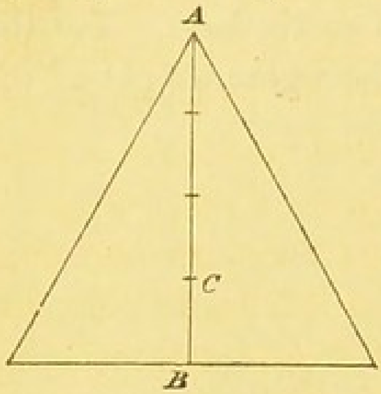
From this fact follows the remarkable circumstance that the fluid, in a cubical vessel, produces a total amount of pressure three times as great as its own weight; for if this = 1, and as upon each of the four sides it produces a pressure equal to half that on the base, $\frac{1}{2} \times 4 = 2$; and upon the bottom a pressure equal to its own weight, the total pressure exerted by it must be $2 + 1 = 3$.

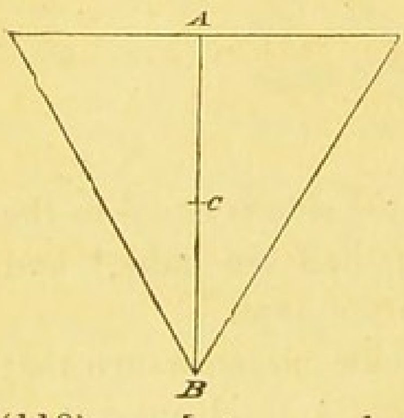
128. The point where all these pressures (121-7), in a mass of fluid, are equally balanced, is termed the *centre of pressure;* this would be identical with the centre of gravity

* Euclid, B. ii. props. 28 and 40.

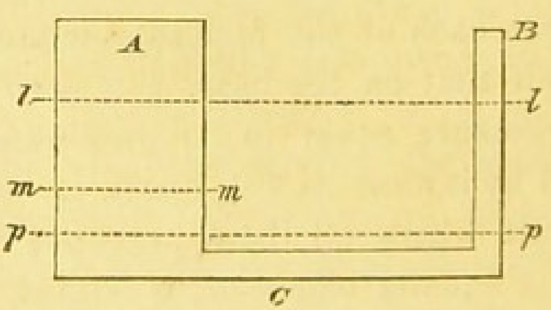
(31), if the lower layers of fluid were not compressed by the weight of those above them, on which account it is always lower than this point. In a vessel whose sides are parallelograms, the centre of pressure is found by bisecting the horizontal sides, by the line AB, and dividing GD into three equal portions by the lines *ef*; produce *f* to *g*, and the point where this line intersects AB will correspond to the centre of pressure C. In a triangular vessel supported on its base and filled with fluid, the centre of pressure is at one fourth of the vertical line AB, reckoning from the base, viz. at C. In a similar vessel resting on its apex, the centre of pressure is at C, in the middle of the vertical line AB.





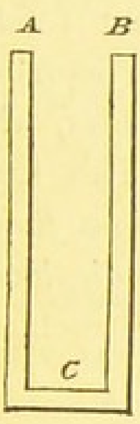


129. When several vessels, of the same or different sizes, communicate together, the same conditions of equilibrium obtain, as when fluids are contained in a single vessel, (119). Let AB be two vessels connected by the



tube C, on pouring water into them up to the line *ll*, it will be found to present a level surface in both; and the fluid in each will be at the same elevation; for if the water in A, instead of being at *l*, was at *mm*, it is obvious that the layer of fluid *pp* would be submitted to unequal pressure, being in B pressed by the long column *lp*, and in A pressed only by the shorter column *mp*, and consequently equilibrium could not exist (119). Therefore the particles of fluid acted upon by the strongest force will move, and attain a state of rest only when the level of the fluid is the same in both vessels. The only circumstance introducing the slightest exception to this law is capillarity (16), by which, if one of the vessels, as B, in the above figure be very narrow, the water, or other fluid, will have a tendency to rise to an higher elevation than the fluid in A.

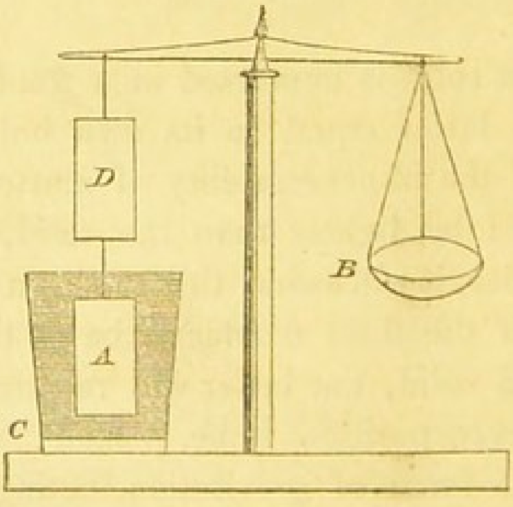
130. The above law applies only when the communicating vessels are filled with the same fluid; for if fluids of different densities incapable of mixing, as water and mercury, be used, the elevations acquired by each will be found to be in the inverse ratio of their specific gravities. Let mercury be poured into the tube AB until the horizontal portion C becomes filled, then pour water into B, and it will be found that, to raise the mercury in A to the height of one inch, a column of water, rather more than 13·5 inches high, will be required in B; the specific gravity of mercury, as compared to water, being as 13·59 to 1.



131. When a solid is immersed in a fluid, it displaces a quantity of the latter equal to its own bulk, a legitimate consequence of the impenetrability of matter (2). If this quantity of fluid be lighter than the solid, the latter will sink, but if heavier, it will swim: this has been already alluded to (29). But if the fluid displaced be of the same weight as the immersed solid, the latter will remain at rest in the fluid, in whatever position it be placed; a circumstance arising from the force of gravitation acting equally upon

the solid and the fluid displaced, the quantities of matter in each being equal (27). Fishes appear to be in this state of equilibrium when immersed in their own element; and for the purpose of enabling them to preserve this state at different depths they are provided with an air-bladder, by compressing or expanding which, they are enabled to acquire the same density as that of the water. At a very great depth, the air in this organ becomes considerably condensed, and on suddenly rising to the surface it expands; and it occasionally happens that this takes place with such force, that the muscular efforts of the animal are unable to control it, and the organ is ruptured, causing an extravasation of air into the surrounding tissues. The known hydrostatic toy, in which a hollow glass figure, partly filled with water, floats or sinks in a vessel of water by pressing the piece of caoutchouc with which the latter is covered, is a popular illustration of these facts.

132. The well-known hydrostatic principle that solids, immersed in fluids, displace a quantity of the latter equal to their own bulk, was first observed by Archimedes, who studied it with no less industry than success. This sage moreover discovered *that a body, when immersed in a fluid, loses a portion of its weight equal to that of the displaced fluid.* The most satisfactory mode of proving the correctness



of this important law is, by suspending from one of the arms of a balance a hollow cylinder, D, having a cylindrical mass of any substance, A, capable of exactly fitting into it, hanging from it by means of a thread. Place weights in the scale-pan B until the solid cylinder A and the hollow one D are exactly counterbalanced; then pour water into the vessel C until A is completely immersed, and immediately the pan B will preponderate, the solid cylinder appearing to have lost a considerable portion of its weight; pour water into the vessel D until it is quite full, and as soon as this is done the balance will once more be in equilibrio. Now, as the cylinder D is of such a size that the solid mass A will exactly fit into its interior, it follows that the water with which D is filled is precisely equal in bulk to the solid A; proving most satisfactorily that the apparent loss of weight suffered by A, on being immersed in water, is precisely equal to the weight of a mass of fluid equal in bulk to itself. The apparent loss of weight of the mass A, observed on immersing it in water, arises from the upward pressure (124) of the fluid supporting the immersed solid, and opposing, to a certain extent, the attraction of gravitation (25).

133. The principle of Archimedes (132) affords a ready mode of determining the *specific density or gravity* (24) of any substance; for when a substance is immersed in water and weighed, it as above stated, suffers an apparent loss of weight equal to that of its own bulk of water; then, by knowing this, and the absolute weight of the body when weighed in air only, we have all the elements for calculating the density of any substance; for the density of any body is equal to its bulk, multiplied by the quantity of matter, or number of atoms it contains. Water is generally assumed as a standard to which all the specific weights of bodies are referred, and its specific gravity is assumed as 1 or 1000; thus, if a body is said to be of specific gravity 11·50, all that is meant, is that a quantity of water, weighing 1000 grains,

is exactly equal in bulk to a mass of the substance weighing 1150 grains. A cubic inch of water, at the temperature of 40°, weighs 252·953* grains, or a cubic foot 437102·4946; to obtain the weight of a cubic inch or foot of any substance, it is only necessary to multiply its specific gravity, by the weight of an equal bulk of water.

134. The best mode of obtaining the specific gravity of a solid heavier than water, is to suspend it by a hair, or piece of fine platinum wire, from a hook fixed in the bottom of one of the pans of a balance, and by placing weights in the opposite scale ascertain its exact weight, then immersing the solid completely in water it will appear to lose weight (132), and ascertain its exact weight when thus immersed. Subtract the weight of the substance in water from its weight in air, and divide the latter by the difference, the product will be the specific gravity required.

Ex. A piece of copper weighed in air 2047 grains, and in water 2024 grains; then $2047 - 2024 = 23$, and $2047 \div 23 = 890$, the specific gravity required.

135. If the substance be lighter than water, tie it to a piece of any heavy solid, whose weight in air and water is known, sufficiently large to sink it in water; weigh the compound both in air and water, and ascertain the loss of weight; then, knowing the weight lost by weighing the heavy body by itself in water, ascertain the difference of these losses, and with this quotient divide the weight of the light body, the result will be its specific gravity. The rationale of this process is sufficiently obvious, for the last loss is = the weight of a quantity of water, equal in bulk to the heavy and light bodies together; and the first loss is = the weight of water, equal in bulk to the heavy body, and consequently their difference is equal to the weight of a mass of water of the same bulk as the light body.

* At the temperature of 62° the cubic inch of water weighs 252·458 grs., the logarithm for which is 2·40219.

Ex. A substance weighed in air 600 grains; tied to a piece of copper, it weighed in air 2647 grs. and in water 2042 grains. The copper itself losing 23 grains when weighed in water; then 2647 — 2011 = 636, and $600 \div \overline{636 - 23}$ = ·978, the specific gravity of the substance.

136. If the solid be soluble in water, it must be weighed whilst immersed in some fluid incapable of dissolving it, as alcohol, oil of turpentine, &c., and its specific gravity as compared with the fluid ascertained; and knowing the specific gravity of the fluid employed, a simple rule of proportion will show the specific gravity of the solid as compared with water.

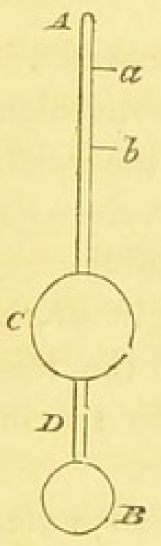
137. The specific gravity of a fluid may be discovered in several ways, the readiest is to take a phial of convenient size and carefully counterpoise it. Ascertain first the weight of water required to fill it, and then the weight of the same phial full of the fluid under examination; and, on subtracting from the latter the weight of the bottle, the weight of the fluid will be ascertained. Divide the weight of the fluid by that of the water, and the quotient will be the specific gravity.

Ex. A counterpoised bottle held 500 grains of water, and 412 grains of alcohol, then 412 ÷ 500 = 0·824 the specific gravity required, for 500 : 1000 :: 412 : 824. Another and very convenient mode of finding the specific gravity of a fluid is founded directly on the fact of solids displacing a bulk of fluid equal to their own (132). Take a glass ball whose loss when weighed in water is known, then weigh it while immersed in any other fluid, and, subtracting this from its weight in air, ascertain this fresh loss of weight. Then its loss when weighed in the fluid, divided by its loss when weighed in water, will be the specific gravity required.

Ex. A glass ball lost 30 grains when weighed in water, and 24 when weighed in alcohol, and 24 ÷ 30 = 0·800, the specific gravity of the fluid for 30 : 1000 :: 24 : 800.

138. The specific gravity of fluids is frequently very conveniently ascertained by means of the aerometer or hydrometer; an instrument whose mode of action depends upon the fact of solids of a given weight sinking deeper in light, than in heavy fluids.

These instruments are made of various materials, as metal, ivory, and glass, according to the uses for which they are intended. Their action is always confined within a very limited range, unless they are of inconvenient sizes, and their indications are by no means mathematically correct, still, for very many practical important purposes they are extremely useful. As instruments of this class are frequently useful to the physician in his examination of certain animal secretions, it will be not altogether useless to describe the mode of graduating them. Procure a thin glass tube blown into the shape of the figure AB, and about five inches in length, place in the narrow tube AC a thin slip of paper, and pour in mercury until, when immersed in distilled water, the whole instrument will sink to within half an inch of its top; then thrust, by means of a wire, a fragmen, of cork and a few pieces of sealing-wax into the smaller tube D; by holding it near the flame of a candle, melt the wax, and then allow the whole to cool. In this manner the mercury will be kept in the ball B, without any danger of its falling out on inverting the instrument. Replace it in water, and very carefully mark with a file, the point where the stem A is intersected by the surface of the fluid; let this be *a*, then immerse it in a solution of salt, whose specific gravity is known; suppose this to be 1·030, and mark with a file the point where the stem is intersected by the surface of the solution; let this be *b*. With a pair of compasses take the distance *ab*, on a slip of paper of the same size as that previously placed in A, and divide this into thirty equal parts, and from the same scale



divide the whole length of the paper until it has sixty equal parts marked upon it. Then introduce this paper into the stem A, in place of the first piece, and push it down until the mark *a* corresponds to zero, or 0 on the paper scale; when this is done the latter may be retained in its place by a little varnish or gum; and the top being closed by the blow-pipe, the instrument is completed. To ascertain the specific gravity of any fluid by it, immerse it in the fluid, and note the graduation to which the level of the fluid corresponds, add 1000 to this, and the product is the specific gravity of the fluid very nearly; thus, if the stem sinks to 15, the specific gravity of the fluid is 1015. It must be borne in mind that, in all experiments in which the object is to ascertain the specific gravity of bodies as compared to water, the latter must be distilled, and of the temperature of 60° Fahrenheit.

139. The specific gravity of a gas is ascertained in a similar manner as that of a liquid (137), only the standard of comparison is changed, atmospheric air being here assumed as unity, or, to avoid decimals, 1000. Let a copper or glass flask, furnished with a good stop-cock, be weighed when filled with air, and then after being exhausted by means of an air-pump as perfectly as possible (152). The difference of these weights will give the weight of air contained by the flask. Then fill the flask with the gas under examination, and carefully weigh it, this weight *minus* that of the flask will give the weight of the gas. The weight of the gas divided by that of the same bulk of air will give the specific gravity of the former as compared to the latter.*

Ex. A glass flask, carefully counterpoised, held 5·7 grains

* For a most elaborate and correct account of the mode of determining the specific gravities of gases and vapours, I beg to refer the student to page 395 of the first volume of Liebig's and Poggendorff's invaluable "Handwörterbuch der reinen und angewandten Chemie."

of atmospheric air and 5·40 grains of olefiant gas; the specific gravity of the latter was therefore

$$5{\cdot}4 \div 5{\cdot}7 = 0{\cdot}982, \text{ for } 5{\cdot}7 : 5{\cdot}4 :: 1000 : {\cdot}982.$$

140. The following questions will illustrate the value of the knowledge of the specific gravities of the bodies.

A. What is the weight of a cubic inch of copper?

The specific gravity of copper being 8·90 (134), or more exactly 8·879, we have to multiply this by the weight of a cubic inch of water, which at 62° is 252·458 grains, to answe the question: therefore, by logarithms,—

$$\begin{aligned} \log 252{\cdot}458 &= 2{\cdot}40219 \\ \log 8{\cdot}879 &= {\cdot}94836 \\ \hline 3{\cdot}35055 &= 2241{\cdot}5 \text{ grains.} \end{aligned}$$

B. What is the weight of a cubic foot of marble, of specific gravity 2·838, in ounces?

The number of ounces which a cubic foot of water at 62° weighs are 997·1369691, this is generally assumed at 1000 ounces to avoid decimals, then 1000 × 2·838 = 2838, the weight in ounces of the cubic foot of marble: to ascertain the *exact* weight, we may proceed thus:

$$\begin{aligned} \log 997{\cdot}1369691 &= 2{\cdot}99875 \\ \log 2{\cdot}838 &= {\cdot}45301 \\ \hline 3{\cdot}45176 &= 2829{\cdot}8 \text{ ounces.} \end{aligned}$$

TABLE OF SPECIFIC GRAVITIES.

WATER = 1,000.

Metals.

Potassium	0·865
Sodium	0·973
Tellurium	6·115
Antimony	6·712
Zinc	7·100
Cast iron	7·207
Tin	7·291
Cobalt	7·812
Steel	7·816
Copper, cast	8·788
——— wire	8·879
Bismuth	9·822
Silver	10·474
Lead	11·352
Gold	19·258
Platinum, forged	20·337
——— laminated	22·069
Mercury	13·586

Organic Bodies.

Wood of Poplar	0·383
Larch	0·498
Cedar	0·561
Cypress	0·598
Lime	0.604
Ash	0·845
Beech	0·852
Oak	0·925
Cork	0·240
Ivory	1·826
Beef bones	1·656
White wax	0·960

Inorganic non-metallic Bodies.

Agate	2·590
Amber	1·078
Sulphur, native	2·033
Glass, crown	2·488
——, flint	3·329
Rock crystal	2·653
Marble of Paros	2·838
Diamonds	3·501 — 3·531
Oriental rubies	4·283

Liquids.

Ether	0·715
Alcohol	0·792
Rectified spirit	0·837
Oil of turpentine	0·870
Oil of olives	0·915
Sea-water	1·026
Milk	1·030
Nitric acid	1·503
Ammonia	0·960
Sulphuric acid	1·845
Acetic acid	1·063
Oil of cinnamon	1·043
Oil of cloves	1·036

Gases.

ATMOSPHERIC AIR = 1,000.

Ammonia	0·590
Carbonic acid	1·527
Carbonic oxide	0·972
Chlorine	2·500
Cyanogen	1·805
Hydrogen	0·069
Nitrous oxide	1·527
Nitrogen	0·972
Oxygen	1·111
Sulphurous acid	2·222
Sulphurated hydrogen	1·180

Weights of given bulks of water and air, for calculating the absolute weights from the specific gravities of bodies (140):

Cubic inch of distilled water, (bar. 30, therm. 62)			LOGARITHMS.
	in grains	252·458	2·40219
.... foot	in ounces avoird.	997·1369691	2·99875
	in pounds ditto	62·3210606	1·79463
Weight of 100 cubic inches of air,	in grains ditto	30·49	1·48416

CHAPTER VII.

GENERAL PROPERTIES OF FLUIDS AT REST (AEROSTATICS).

141. THE great mass of gaseous matter, surrounding our earth and extending to a considerable distance from it, is termed the *atmosphere* or *atmospheric air*. This, like the denser fluids, obeys laws similar to those treated of in the preceding chapters, with such modifications as its eminently elastic character produces. Like the less elastic liquids, gases obey the attraction of gravitation, and the conditions of equilibrium and equal pressure, explained in the last chapter. Atmospheric air consists, in 100 parts, of

	BY WEIGHT.	BY MEASURE.
Nitrogen	77·50	75·55.
Oxygen	21	23·32.
Aqueous vapour	1·42	1·03.
Carbonic acid	·08	·10.

142. In consequence of the atmosphere being confined to the earth's surface by gravitation (25), we find it much denser near the level of the sea (120), than at any distance above it. As we ascend above the surface of the earth, the density of the atmosphere rapidly decreases; thus, at an elevation of 3 miles, it is $\frac{1}{2}$ the density of the air on the earth's surface; at 6 miles it is $\frac{1}{4}$; at 9 miles, $\frac{1}{8}$; and at 15 miles, $\frac{1}{30}$ of that density: the greatest part of the atmosphere is thus evidently always within 20 miles of the surface of the globe, although,

from certain astronomic phenomena, it is supposed to extend to a distance of 40 or 45 miles; and here is, in all probability, its utmost limit. Dr. Wollaston* has shown that, at this elevation, the attraction of the earth upon any one particle, is equal to the resistance arising from the repulsive power of the medium. Another proof of the finite extent of the atmosphere is found in the fact of the sun, and the planets, being destitute of any similar media surrounding them; for if it be supposed to extend into infinite space, such large masses of matter as the planets, must surely have caused a considerable portion to gravitate towards them. Other philosophers† have supposed that the extreme cold of the upper regions is sufficient to prevent the infinite expansion of the atmosphere. Dr. Dalton,‡ reasoning on one of Newton's propositions,§ has adopted the opinion of Wollaston.

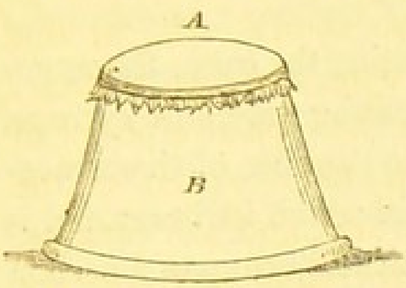
143. The weight of 100 cubic inches of atmospheric air, at 60° Fahrenheit and the barometer at 30 inches, has been computed at 30·92 grains, by Kirwan; at 31·10, by Sir H. Davy; at 30·5, by Sir G. Shuckburgh; and at 30·199, by Mr. Brande.

The extreme elasticity of gaseous substances arises from the intensity of their molecular repulsion, which, instead of being nearly equally balanced, or exceeded, by the intensity of molecular attraction, as in solids and liquids, tend continually to separate the atoms still further from each other, and to press against the sides of a vessel containing them with often sufficient force to rupture it, were this effect not checked by external pressure. Unlike the far less elastic liquids, gases never present a level surface free from pressure, for they tend continually to expand themselves into space, to prevent which, actual force must be exerted.

144. The atmosphere presses upon all bodies immersed therein with very considerable force,—a force which would every instant be sufficient to crush animal structures, if, in obedience to the laws of equal and contrary pressure (124),

* Phil. Trans. 1822, p. 90. † Phil. Trans. 1823.
‡ Phil. Transactions. 1826. § Principia, Book ii. prop. 2, p. 292.

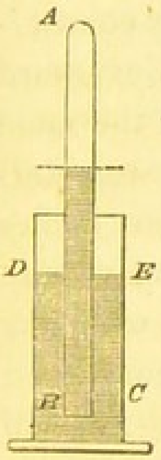
this effect were not prevented. Let a piece of bladder be firmly tied over the end A of the strong glass vessel AB, it remains perfectly flat, and gives no evidence of any force pressing upon it, for the reasons above stated; but place the lower part of the vessel on the plate of the air-pump, and exhaust the air from beneath the bladder; the upward pressure which prevented the weight of the atmosphere from exerting its effect becomes removed, the bladder curves inwards under its influence, and at last gives way with a loud report.



If a plate of glass were placed on A, instead of the bladder, it would, if sufficiently thin, become broken by the pressure of the atmosphere. This pressure is, in round numbers, equal to fifteen pounds upon each square inch of surface.

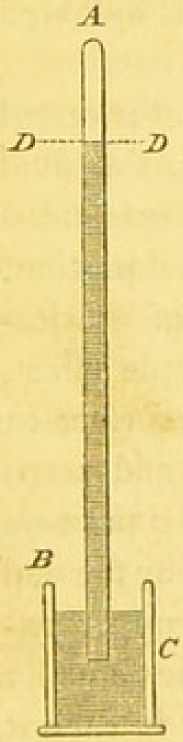
145. Atmospheric pressure is exerted upon everything on the surface of our globe, on mountains and lakes, on continents and oceans, nothing is exempt from its force, any more than from gravitation, to which this pressure is indebted for its origin.

If a glass tube AB be partly filled with water and inverted in the vessel C, filled also with water, the fluid will not fall in the tube, but remain suspended at a higher level than that of the external portion, in appearance, contrary to the force of gravitation, of which it is, however, the simple effect. For the atmosphere, pressing upon the surface DE of the water in C, acts upon that in A, and keeps it elevated in the tube; for the opposing pressure necessary for its equilibrium, is cut off by the end A being closed. On perforating the upper extremity of the tube, the pressure of the air becomes equally exerted on the water in A and C, and accordingly in each it acquires the same level. If the tube AB be of any length under about thirty feet, the pressure of the atmosphere will be sufficient to keep it full of water, when it had been pre-



viously filled with, and inverted in, a cistern full of that fluid.

146. If, instead of filling and inverting the tube, the upper end be connected with a good exhausting pump or syringe, and the air in its interior removed, the pressure of the atmosphere upon the water in the cistern, in which its lower end is immersed, will force that liquid into its interior, up to a certain elevation, averaging about thirty-three feet.* At this elevation, the column of water becomes balanced by the pressure of the atmosphere; and, of course, any change in the pressure of the latter will be attended by a corresponding change in the elevation of the water in the tube, forming *a barometer*, or measurer of aerial pressure. An instrument, constructed in this manner, has been erected in the hall of the apartments of the Royal Society at Somerset House, and its indications are highly interesting and delicate, but, in consequence of its length, it becomes extremely inconvenient, and accordingly the mercurial barometer is universally used. This is constructed on the same principle as the water barometer, but the tube



being filled with a fluid 13·58 times heavier than water, is required to be but $\frac{1}{13\cdot58}$ times as long as that of the water-barometer. A column of mercury, thirty inches in height, exactly counterbalancing, at average pressure, the downward force of a column of atmospheric air of the same diameter. To construct a mercurial barometer, select a glass tube AB, about thirty-two inches in length, and fill it carefully with very pure murcury; then, closing the end B, with the finger, immerse it in the vessel of mercury C; on removing the finger, the mercury in AB will fall to a certain distance, leaving a column, in the tube, of a height corresponding to the atmospheric pressure at the time.

* Boyle's works: Dr. Shaw's edition, 1725, vol. ii, p. 486.

The space above DD, unfilled with mercury, is the nearest approach to a perfect vacuum which can be procured by art; for, on depressing the end B deeper in the mercury, the whole tube becomes completely filled, the fluid metal again falling, on elevating the tube. The space above DD contains a small quantity of mercurial vapour, and is termed the Torricellian vacuum, from its having been first observed by Torricelli, a pupil of Galileo, in 1643. The height of the mercury in the tube, is always measured from the surface of that in the cistern C; and this elevation is the measure of atmospheric pressure at the time. The elevation assumed as the standard in this country is thirty inches, and to this, all measurements and weights of gaseous bodies are referred.

Several modifications of the barometer are in use, as the syphon, and wheel barometers; their theoretical action is the same as that of the straight tube above described. In the construction of these instruments, great care is required in freeing the mercury from air; this is best effected by boiling the fluid metal, and introducing it into the tube whilst warm.

147. To obtain the mean diurnal height of the barometer, it is necessary to observe the height of the column of mercury every hour, during twenty-four hours, and to take the mean of these observations. This tedious process can, to a great extent, be avoided; for a French philosopher, M. Ramond, has proved that at noon, the elevation of the mercury corresponds almost exactly with the mean diurnal height.

148. The column of mercury, in the barometer, undergoes several regular variations in the course of the day; they are termed *horary variations*. From the observations of Baron Humboldt, made at the equator, the maximum elevation takes place at nine o'clock in the morning; past this hour it becomes less, until four, or half-past four in the afternoon, when it attains its minimum; it again ascends to eleven at night, when it reaches its second maximum; and once more descends to four o'clock in

the morning, after which it reascends until nine. Thus, every day, the mercurial column is at its lowest elevation at four in the morning and afternoon, and at its greatest, at nine in the morning and eleven in the evening. The amplitude of these variations are but small, being calculated by Humboldt at 0·07874 inch only. In Europe, these horary variations become marked by changes of atmospheric pressure, depending upon accidental causes, which, at the equator, are nearly without action on the barometer. As far as these horary variations have been observed in our northern latitudes, the maximum in winter appears to be at nine in the morning, the minimum at three in the afternoon, and the second maximum at nine in the evening. In the summer, the maximum elevations are at eight in the morning, and eleven at night; the minimum being at four in the afternoon. In spring and autumn, the times of these variations are intermediate with those of summer and winter.

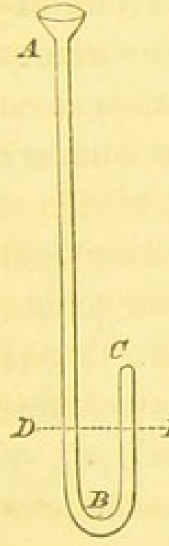
149. Among many important uses of the barometer, must be mentioned its application for the purposes of measuring heights; as we ascend from the level surface of the earth, the column of atmosphere, pressing on the mercury, becomes virtually shorter, and consequently the fluid metal falls in the tube.

The increase of rarity of the air, as we ascend, has been already mentioned (142); the following is a view of the corresponding subsidence of the mercury in the barometer:

At 3	miles above the level of the sea, the mercury stands at	15 inches.
6	. . . .	7·5
9	. . . .	3·75
15	. . . .	1·0

Hence the subsidence of mercury in the barometer, as we ascend mountains or other elevations, affords valuable data for calculating their vertical height.

150. From the density of the atmosphere diminishing as we recede from the earth, we learn that gases increase in volume, as the force acting upon them diminishes in intensity. This has been long recognized as the *law of Marriotte*, and is concisely stated thus, "*the volumes of gases are in the inverse ratio of the pressures which they support.*" The truth of this is readily demonstrable: let a glass tube ABC,

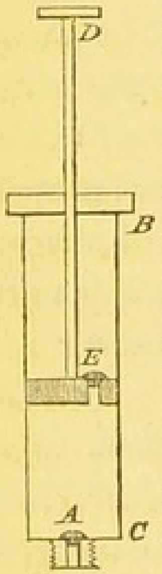


having its end C carefully closed, have some mercury poured into it, and by inclining the tube, allowed to flow into the shorter leg, until it stands at the same level in A and C, as up to the dotted line DE; the space CE will, consequently, contain a certain bulk of atmospheric air, submitted to the ordinary pressure of the air through the open tube A. To compress this air into one half its volume, pour mercury into A, until it stands at thirty inches above the line DE; the air in C will thus be submitted to a pressure of two atmospheres: one, of the atmosphere itself pressing on the mercury in A; the other, of the thirty inches of mercury in the tube which, as already stated (146), corresponds to the pressure of one atmosphere; and accordingly the air in C becomes compressed to half its original bulk. This law has been verified under a pressure of twenty-seven atmospheres. A necessary consequence of the law of Marriotte is, that *the density of gases are in proportion to the pressure to which they are exposed;* and consequently, under a pressure of 770 atmospheres, air would become as dense as water.

151. In consequence of the atmosphere, in average states, being capable of supporting thirty inches of mercury, it is easy to calculate the pressure upon each square inch of surface exposed to its action, by calculating the weight of a column of mercury thirty inches high, and one inch square. This will be found to be very nearly equal to

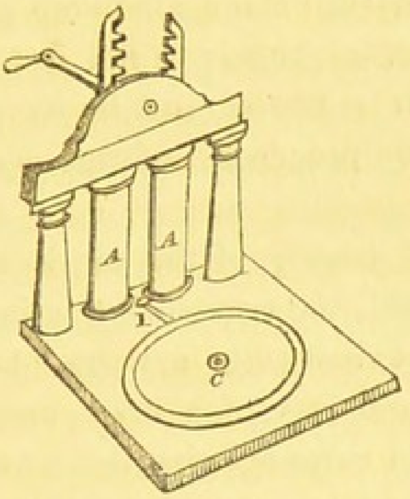
fifteen pounds, which is therefore assumed as the amount of pressure on every square inch of surface exposed to the atmosphere. This pressure corresponds very nearly, to that of a column of atmospheric air five and a quarter miles in length, if of uniform density; but, as this diminishes in proportion as we rise above the level of the sea, the air really extends to a much greater elevation (142). If the surface of an adult, be considered as equal to 2000 square inches, the pressure exerted on his body by the atmosphere, is equal to the enormous amount of 30,000 pounds, a force more than sufficient to crush him to atoms, were it not united by equal and contrary pressure.

152. For the purpose of examining the effects resulting from atmospheric pressure, an exhausting syringe, or air-pump, becomes a necessary piece of apparatus. These



instruments are constructed on the same principles: the former consists of a barrel, BC, of metal, furnished with a screw at C, for the purpose of connecting it with any apparatus required; at A is a valve, opening upwards. The piston ED moves air-tight in the barrel, perforated at E, and there furnished with a valve, also opening upwards. On connecting this syringe, by means of the screw C, with any piece of apparatus, let E be drawn up to B, and then depressed; the air inclosed between E and A will escape through the valve E: on elevating the piston, a vacuum is formed between E and A; air rushes in through A, to fill this; and on again depressing the piston, this escapes through the valve E, and so on. The air, in the vessel connected with C, becoming each time more rarefied, and ultimately affording an approach to a vacuum.

As this process is extremely tedious, and in proportion as the air becomes more rarefied, the external atmosphere, pressing on the piston, renders it laborious to elevate it,—this syringe has given way to the air-pump, constructed with two similar barrels, connected by a tube with a perforation in the centre of a smooth plate of brass, on which strong glass vessels, called receivers, are fitted air-tight. By working the



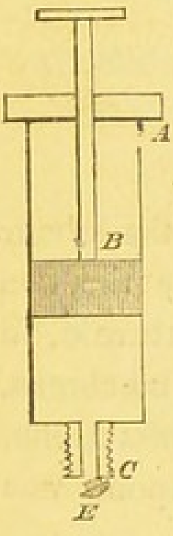
pistons, by means of a cog-wheel and rackwork, the labour of exhaustion becomes much diminished. AA are the two barrels communicating by the tube I, with the aperture C, in the centre of the air-pump plate. In the earlier machines, the barrels were connected directly with a large glass globe, in which the substance to be experimented upon, was placed.*

153. As, by means of these instruments, the air, in a vessel connected with them, becomes only excessively rarefied, never approaching to a *perfect* vacuum, it is frequently a matter of importance to measure the degree of rarefaction of the included air; for this purpose, the open top of a barometer tube is connected with the tube I, its lower end being plunged in mercury. On placing a receiver over C, and exhausting the air, the mercury is forced up into the tube by the pressure of the atmosphere; and the nearer its height corresponds to that of the barometer, at the time of the ex-

* Boyle's Works, vol. ii. p. 408.

periment, the nearer the air in the receiver approaches to a state of perfect exhaustion. Another mode of gauging the degree of exhaustion is, by immersing the end of a tube, seven inches and a half in length, in a little vessel of mercury, with which the tube itself has been previously filled; on placing this under the receiver on the air-pump plate, and exhausting the air, the mercury begins to fall in the tube when one fourth of the air is removed, and by its continuing to subside, as rarefaction proceeds, informs us of the degree of exhaustion.

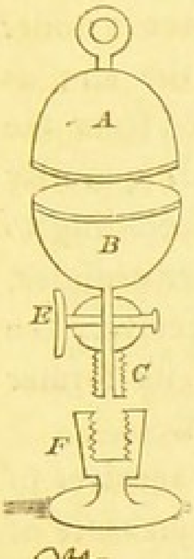
154. When the density of the air is required to be increased, the condensing syringe, the converse of the exhausting syringe (152), is employed. This consists of a brass barrel, furnished at E with a valve opening downwards; a perforation is made in the side of the barrel at A. On screwing this syringe on a strong metallic vessel, and raising B above the opening at A, all the space between B and E becomes filled with air, and, on depressing the piston, this is forced through the valve E, into the vessel screwed on C. On again raising B, air cannot escape through E, because the valve opens downwards; and on depressing the piston, a fresh portion is forced through E into the vessel, and thus the condensation of several volumes of air into a small bulk becomes effected.



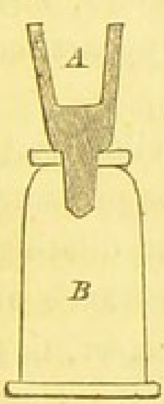
155. By means of these machines, many highly interesting experiments, illustrating the general properties of gaseous bodies, may be performed. The following are examples of these:

Illustrating Atmospheric Pressure.

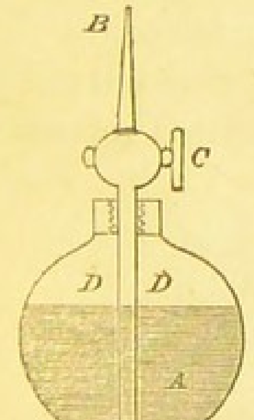
(A.) Place, in close contact, the two brass hemispheres AB, and connect them, by means of the screw C, with the hole C in the air-pump plate (152); exhaust the air from their interior, close the stop-cock E; remove them from the air-pump, and screw on the handle F. On then attempting to forcibly separate A from B, it will be found nearly impossible, by any moderate exertion of strength, to effect this: for they will be pressed together by as many times fifteen pounds as there are square inches on their surface. This apparatus is well-known as the Magdeburg hemispheres, from its having been invented by ~~Otho~~ Otto de Guericke, burgomaster of that town.



(B.) Pour into the wooden cup A, screwed on the top of the receiver B, some mercury, and place the whole on the air-pump plate. On exhausting the air from B, the mercury will be forced through the pores of the wood into the receiver B, in the form of a metallic shower, by the pressure of the external atmosphere.



Illustrating the Elasticity of Air.



(C.) Remove the jet B, from the vessel A, and screw on the condensing syringe (154), having previously half filled A with water; on forcing air into this vessel, it will bubble up through the water, and rise to its surface DD. After working the piston for a few minutes, close the stop-cock C, remove the syringe, and screw on the jet B. The condensed air will press upon the surface of the water in A; and on opening the stop-cock, will force it out in a jet, forming a fountain, often rising fifteen feet high.

(D.) Press together the sides of a bladder, so as to nearly empty it of air, and tie it tightly at the neck; place it under a receiver on the air-pump plate, and exhaust the air; as soon as the pressure of the latter becomes removed from the surface of the bladder, the elasticity of the small quantity of air left in it comes into play, and, expanding according to the law of Marriotte, forces the sides of the bladder asunder, and expands it. On readmitting air into the receiver, the small quantity left in the bladder contracts to its former bulk; and causes it to appear as empty as at first.

(E.) Place a vessel of spring water under the receiver of the air-pump, and exhaust the air; as soon as the pressure of the atmosphere becomes removed, the air dissolved in the water, expands by its elasticity, forms large bubbles, and escapes from the water, giving to the latter the appearance of being in a state of slow ebullition.

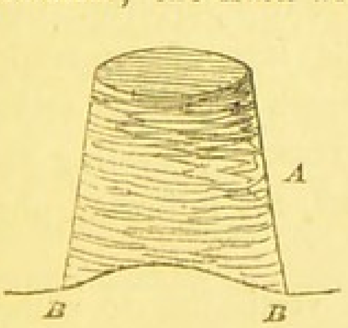
(F.) On placing baked apples, raisins, or shrivelled fruit, under the receiver of an air-pump, and removing the pressure of the atmosphere, the air they contain expands, and dilating the integuments of the fruit, gives them the appearance of ripe plumpness. On readmitting air into the receiver, this artificial and delusive appearance vanishes, and the fruit appears as shrivelled as before the experiment.

CHAPTER VIII.

GENERAL PROPERTIES OF FLUIDS IN MOTION.
(HYDRO- AND PNEUMO-DYNAMICS.)

Pressure against the Sides of Vessels, 156. *Theorem of Torricelli,* 157. *Velocity of Fluid Currents,* 158. *General Law of Currents,* 159—*lateral Reaction of,* 160. *Velocity of Fluid through Narrow Channels,* 161. *Fountains,* 162. *Friction between Fluids and Solids,* 163—*between Fluids only,* 164. *Properties of Gaseous Currents,* 165.—*Apparent Attraction of Disks by Currents of Air,* 166-7.—*Pumps,* 168-171.—*Syphons,* 172-3.—*Hiero's Fountain,* 174.—*Hydraulic Press,* 175.

156. WHEN a fluid is poured into any vessel, the sides of the latter becomes acted upon by two opposed forces, one acting from without to within, and the other in the converse direction. The internal pressure arises from the weight of the column of fluid pressing against the sides (126), and the external force is the pressure of the medium in which the vessel is immersed. If an opening be made in the side of a vessel thus circumstanced, the fluid thus exposed is acted upon by the same forces as pressed against the portion of the side removed; and accordingly, if the pressure from within to without is greater than the opposite pressure, the fluid will flow out of the opening, and obeying the force of gravitation, fall to the earth. But if the external pressure is the most powerful, the fluid will not escape: this may be illustrated by filling a glass-tumbler, A, with water, placing a piece of paper, BB, over its mouth, and carefully inverting it; on holding it in this direction, the fluid will not escape, for the upward pressure of the atmosphere against the paper will exceed the



action of the attraction of gravitation on the water, and accordingly the glass will remain full.

157. Liquids, escaping from orifices in vessels containing them, obey the force of gravitation, and their motion becomes accelerated in a corresponding manner, providing all mechanical obstacles, arising from friction or other causes, be absent. The expression of this fact is known as the theorem of Torricelli, and may be thus stated: *particles of fluid, on escaping from an orifice, possess the same degree of velocity as if they had fallen freely, in vacuo, from an height equal to the distance of the surface of the fluid above the centre of the orifice.* Fluids obey this law without any relation to their density, their velocity solely depending upon the depth of the orifice from which they escape, below the level of the fluid.

158. The velocity of fluids thus escaping from orifices, is, *cæteris paribus*, as the square roots of the depths of the orifices below the surface of the fluid. Thus, calling the velocity of a fluid, escaping from an orifice one foot below the surface, unity; the velocity of a fluid, escaping from a similar orifice 4 feet below the level, will be 2; at 9 feet 3; at 16 feet 4, and so on. From this fact we learn that two vessels perfectly alike, being filled with fluid, and allowed to discharge a certain measure by similar orifices, *one of them being kept quite full by the addition of fresh fluid*, the quantity of water discharged in a given time from the latter vessel, as compared with the quantity escaping from that which was not kept full, will be as 2 to 1.

159. When fluids escape from lateral apertures, they describe parabolic curves, and obey the laws of projectiles (61); and when allowed to escape through a circular orifice pierced in the bottom of a containing vessel, providing the latter be composed of some thin material, the following phenomena are observed:

(A.) The particles of fluid descend vertically, to within three inches of the bottom, and then turn towards the orifice.

(B.) The surface of the fluid gradually falls, remaining horizontal until within a certain distance of the bottom, when it forms a hollow cone, immediately above the centre of the orifice.

(C.) The current of fluid having escaped from the vessel, contracts in diameter at a certain distance from the orifice.

(D.) The greatest contraction of this fluid vein takes place at a distance from the orifice equal to half its diameter: the diameter of the contracted portion of the vein being to that portion nearest the orifice as 5 : 8.

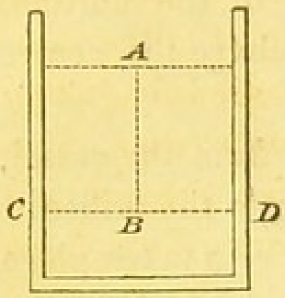
(E.) Beyond this contraction (D) the liquid vein continues to *diminish* in thickness, if moving from above to below, and to *increase*, if moving in the opposite direction.

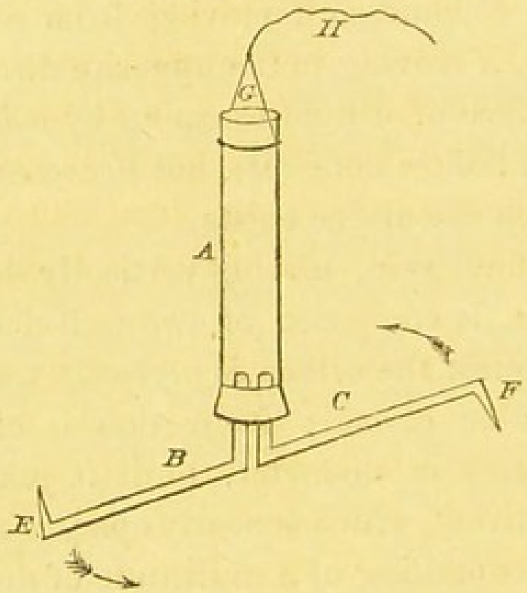
(F.) The surface of a fluid escaping by a *lateral* aperture does not form a hollow cone (B), but becomes depressed on the side in which the orifice exists.

(G.) Every fluid vein, moving vertically downwards from a circular orifice, is composed of two well-defined portions. The portion nearest the orifice is perfectly transparent, like a rod of glass or crystal; its section is circular, and it gradually decreases in diameter, until it joins the second portion of the current, which is nearly opaque, and apparently much agitated, consisting of a multitude of drops, each produced by an annular dilatation of a portion of fluid at the orifice of the vessel, and undergoing during the time of its falling, a series of periodic vibrations, by which each drop alternately elongates and contracts. A series of pulsations thus occur at the orifice of the vessel, their number being in the direct ratio of the rapidity of the current, and in the inverse ratio of the diameter of the orifice; they are frequently sufficiently rapid to produce a distinct musical sound.

(H.) In consequence of the contraction of the fluid-vein (C) (D), liquids escape with equal rapidity from a conical tube, as from a cylindrical one of equal length, providing the truncated apex of the ~~latter~~ former corresponds in situation and section, to the point of *greatest contraction* of the fluid current.

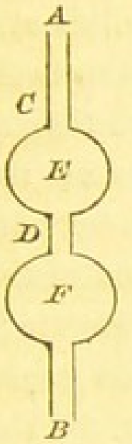
160. In a vessel full of water, the downward pressure of any column, of fluid, as AB, pressing on the horizontal layer CD, acts with a certain degree of force on the sides of the vessel; if then an aperture be made at C, the pressure there becomes null, and fluid escapes, whilst the pressure remains active at D. As the pressure BC against the side is removed, and that against BD continues in action: the vessel, if carefully suspended, will move as if repelled in a direction opposed to that of the current escaping from C.



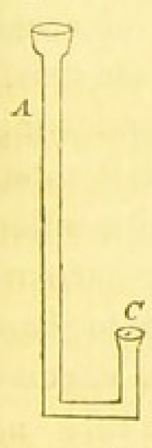


The movement, arising from this reaction against the sides of the vessel, is readily illustrated by means of the apparatus ABC, consisting of a large glass tube, A, closed at both ends with corks; two tubes, CB, bent twice at right angles, are fixed in the lower cork, their ends at EF being bent in opposite directions. Fill A with water, place the cork G in its place, and suspend the whole, by the thread H, from the ceiling. The apparatus will remain at rest, for no fluid can escape, as the pressure of the air against the open ends FE, is more intense than the gravitation of the fluid (156). Remove the cork G, then atmospheric pressure acts on the water in A, forces it through the tubes BC, and escaping at FE, produces a rapid rotation of the apparatus, in a direction contrary to that of the current of escaping fluid.

161. When fluids pass through a tube, or channel, whose section is greater at one part than another, as the same quantity must pass through every part in the same time, the velocity of the liquid is necessarily greater in the narrow, than in the wide parts: thus, if in the tube AB, water be allowed to run through in a constant stream, its velocity at CD will be much greater than at the wide parts EF. The momentum of the fluid will be equal in every part; for as this is equal to the quantity of matter multiplied by the quantity of motion (66), the quantity of fluid contained in CD, is less than in EF, yet its ~~momentum~~ velocity is proportionately greater. For the same reason, when water flows through a funnel, its velocity is as much greater when passing through the tube, as the latter is narrower than the wider part of the instrument; and hence also the current of rivers is more rapid under the arches of bridges than at any other part.

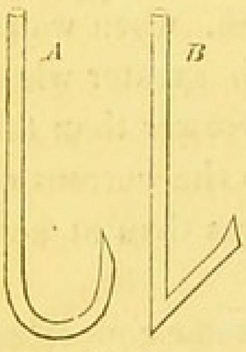


162. Springs and fountains are formed by some concealed reservoir of water escaping through a cleft, or fissure, in the rocks containing the supply of fluid. On the water escaping, it possesses a velocity regulated according to the theorem of Torricelli, and therefore sufficient to project it upwards in the form of a jet d'eau. Artificial fountains are constructed on a similar principle; thus, if the tube AC be filled with water, it will escape from the aperture at C, in a jet rising to an elevation somewhat less than that of the column of water in A; according to the experiments of Marriotte, attaining an elevation of 5 feet, if the column of water in the reservoir be 5 feet 1 inch high. The elevation of the jet d'eau would be equal to the height of fluid in the reservoir, if all friction from angular projections, &c., as well as the resistance of the atmosphere, were removed. The greatest elevations, *cæteris paribus*, is obtained when the fluid escapes through an aperture pierced



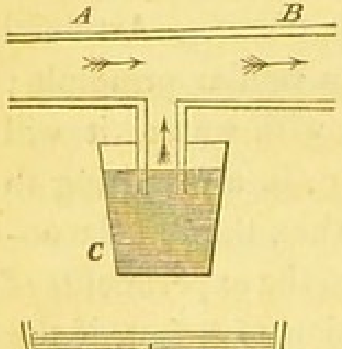
in a thin plate of metal, avoiding all conical terminations, or *ajutages.*

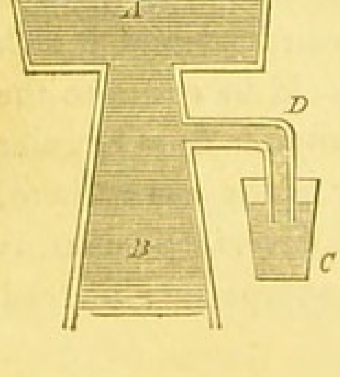
163. Friction is found to take place between solids and liquids, and even between the particles of fluids themselves. A stream of water is always more rapid in the centre than at the sides, as, being deeper there, the current flows on the surface of lower strata of fluid; whilst, in the shallower portions of the river, the water is exposed to the friction of the rough and unequal bottom. In the centre, also, the stream is somewhat more elevated than at the sides; as in its rapid course, it draws the water from the sides of the river, by the friction of their particles, rapidly after it.



In the *ajutage*, or escape-pipe, of a fountain, a similar fact is observed; for if it be bent abruptly, and not with a regular and gradual curve, the passage of fluid becomes much obstructed. Thus, fluids escaping under equal pressures, will rise much higher if passing through the tube A than through B.

164. The friction of particles is illustrated by an experiment of Bernouilli: he found that water, in passing rapidly from the narrow to the wide end of a conical tube, AB, would empty the vessel C, filled with water and communicating with AB, by a small lateral tube. Dr. Barry found that a similar effect was produced by a descending current; for when water was allowed to flow rapidly from A to B, a vessel, C, communicating with AB, by the tube D, became rapidly emptied.





In the circulating system of animals, an arrangement of the blood-vessels is frequently observed in accordance with these principles, so that a current of blood, passing along one vessel, may assist in emptying a lateral branch; or two currents entering a larger trunk at the same point, may thus exhaust the contents of a small vessel entering between them. In the human body, the termination of the left spermatic veins in the renal vein, and that of the thoracic duct in the angle formed by the internal jugular and subclavian veins, afford remarkable examples of such hydraulic arrangements in animal structures.

165. Elastic fluids, or gases, offer no important exceptions to the above laws; in escaping from lateral orifices, they produce a similar reaction against the opposite side, and corresponding tendency to motion, as in the case of denser fluids (160). In the opinions of most philosophers, they also appear to obey the conditions of the theorem of Torricelli, when escaping under the influence of pressure* from orifices, unless the difference between the external and internal pressures be very considerable, in which case they offer some exception to this law (157).

It is also extremely probable that, like denser fluids, gases undergo, when escaping from apertures, a contraction in the diameter of the current; the area of the section of this contraction appears to be equal to that of the orifice through which the gas is escaping, multiplied by the decimal 0·61 or 0·62.

166. One very remarkable phenomenon, connected with the escape of a current of air under considerable pressure, must not be passed over silently. M. Clement Desormes†

* The following formula is Bernouilli's expression for the velocity of an escaping current of gas:

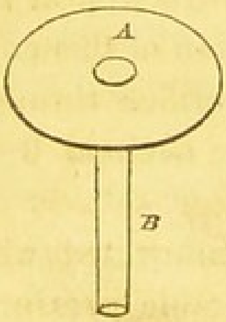
$$v=\sqrt{2k\frac{(p-p')}{p}}$$

v = velocity of the gas; p = internal, and p' = external, pressure; and $2k$ = a coefficient equal to 155610 for gases at the temperature of 32° Fahrenheit.

† Annales de Phys. et Chim. xxxvi. p. 69.

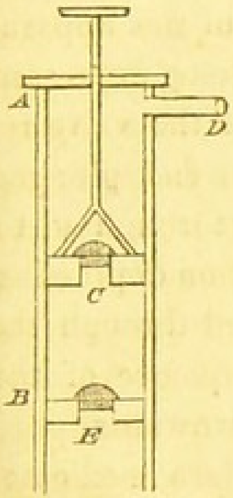
has observed, that when an opening, about an inch in diameter, is made in the *side* of a reservoir of compressed air, the latter rushes out violently; and if a plate of metal or wood, 7 inches in diameter, be pressed towards the opening, it will, after the first repulsive action of the current of air is overcome, be apparently attracted, rapidly oscillating within a short distance of the opening, out of which the air continues to emit with considerable force. This curious circumstance is explained on the supposition, that the current of air, on escaping through the opening, expands itself into a thin disk, to escape between the plate of wood or metal, and side of the reservoir; and, on reaching the circumference of the plate, draws after it a current of atmospheric air from the opposite side, in a manner, probably, analogous to the case of friction between particles of liquids already described (164). The plate thus balanced between these currents remains near the aperture, and apparently attracted by the current of air to which it is opposed.

167. A similar phenomenon, and apparently explicable on similar principles, is exhibited by means of a glass tube, B, fixed at one end into a card-board disk, A. Let a piece of card-board be placed over the end of the tube, and rest on the disk A. Then, on placing the end B in the mouth, and blowing forcibly through it, the piece of card resting on A will be slightly agitated, but no force the person who blows through B can exert, will enable him to displace it from the aperture A. It is, in fact, virtually attracted, in the same manner as the wooden or metallic disk, in the experiments of Desormes (166).



168. The application of the physical properties of fluids to the purposes of domestic economy, and the wants of civilized life, are extremely important, and afford some impor-

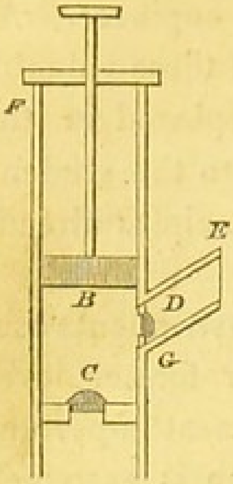
tant objects of study to the mechanic and engineer. An outline of the mode of action of a very few of these valuable presents of science to art, will not be misplaced in this chapter, as they will afford an opportunity to the student, of explaining their mode of action on the principles already laid down.



169. Among the various instruments used to elevate fluids above their former level, those termed *pumps* are the most important. Their theoretical construction is extremely simple: they may be divided into two chief sections; the first including the sucking and lifting; the other, the forcing pumps.

The sucking or suction pump, as it is incorrectly termed, consists essentially of a hollow cylinder, AB, having a valve, E, opening *upwards*, fixed in its lower extremity. A piston, C, furnished with a valve also opening upwards, moves in the interior of the cylinder. If the lower end of the pump be immersed in water, and the piston be depressed to E, the air between CE will escape by the valve in C, and on elevating the piston, a partial vacuum is formed below C; which the water rushes in, through E, to supply. On once more depressing C, this water elevates the valve in the piston, and passes through it, so that on again elevating C, a column of water is raised with it, which eventually escapes through the side tube, or spout, D. On thus continuing alternately to raise and depress the piston, water may be raised from the reservoir in which the lower end of the pump is placed. The action of the lifting pump is so similar, that a distinct account of it is unnecessary; as usually constructed, it differs chiefly, from the pump just described, in the piston entering the cylinder from below, instead of from above.

170. The forcing pump differs from the last in the posi-



tion of its valves: the piston B moving air-tight in the cylinder FG, as in the sucking pump, but has no valve. A valve opening upwards is fixed in the lower part of the cylinder; and at G, a lateral tube, GE, is fixed, having a valve, D, opening upwards. The *rationale* of the action of this apparatus is very obvious: on B being depressed to C, the air is forced through the valve D; and if the pump has its lower end plunged in water, on raising B, the fluid will rush in through C, to supply the partial vacuum thus formed. And on depressing the piston, this portion of water will be forced through the valve D out of the side tube GE, as, in consequence of the valve C opening upwards, it cannot escape downwards.

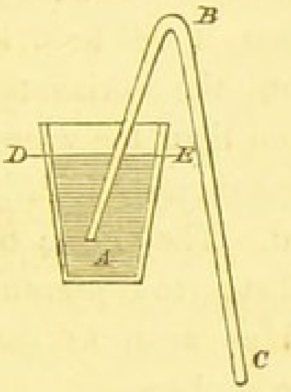
171. That most valuable acquisition to modern medicine, the well-known stomach-pump, is an instrument of this description; the tube introduced into the stomach being alternately connected to the lower end, or the side tube E, according as it is required to inject fluid into, or to empty the contents of the stomach. A glance at the construction of these pumps will be sufficient to point out their similarity to the air-pump (152): in the ordinary pump, on raising the piston, water instead of air rushes in, and, on that account, the valves do not require that excessive care in their construction, which is necessary for the proper action of a good air-pump.*

In all kinds and modifications of pumps, or other instruments by which water is raised above its former level by means of atmospheric pressure, it must be recollected that

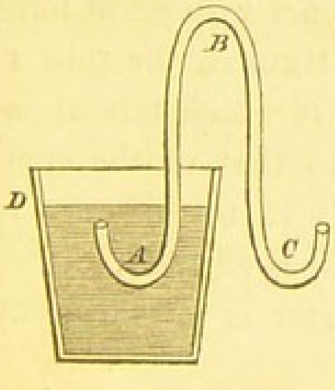
* A beautifully-constructed syringe, on the principle of the forcing pump, has lately been contrived by Mr. Read, the well-known inventor of the stomach-pump; in which the valves (which are of metal) are so well arranged, that the apparatus answers both as a pump for liquids and gases. This apparatus holds out the prospect of affording as important aid in certain cases of asphyxia, by removing the noxious gas from the air-passages, as it has already effected, in removing poisons from the stomachs of those who had inadvertently, or intentionally, swallowed them.

they are limited in action to a distance of about 32 or 33 feet (146) above the level of the water they are acting upon, as a column of water of that length is very nearly equal in weight to the pressure of the atmosphere.

172. The well-known hydraulic instrument, the syphon, consists, in its simplest form, of a bent tube, ABC, having one of its branches longer than the other. On immersing its shorter leg in a vessel of water, applying the mouth to C, and exhausting the air, the pressure of the atmosphere on the fluid DE will force it to ascend in the tube: as soon as this has become filled with water, remove the end C from the mouth, and the water will continue to flow through the syphon until the vessel is emptied. The theory of its action is simple: both legs being filled with water, the attraction of the earth acts upon the fluid in C, and, drawing it downwards, empties the tube; a vacuum would thus be produced if the atmospheric pressure upon DE did not force the fluid up to fill it; the leg C thus again becomes full, and being emptied as before the fluid continues to flow until the vessel is exhausted. If the longer leg of the syphon be immersed in the water instead of the short one, and it be filled with the fluid by exhausting it with the mouth, the upward pressure of the air against the water in the shorter leg will be sufficient to drive it back into the vessel: consequently, no syphon will act, unless the leg outside the vessel be longer than that immersed in the fluid.

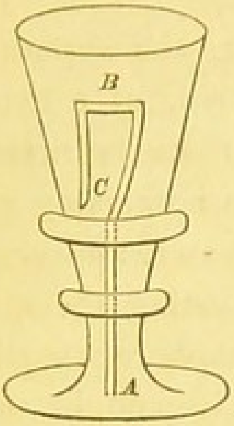


173. A tube, ABC, with its extremities curved upwards, is an useful modification of the syphon; its action is readily understood. Being filled with water, and one of its legs immersed in the vessel D, the column of fluid above A will press upon the water in the extremity of the tube, and no corresponding pressure being applied to the fluid in C, it overflows

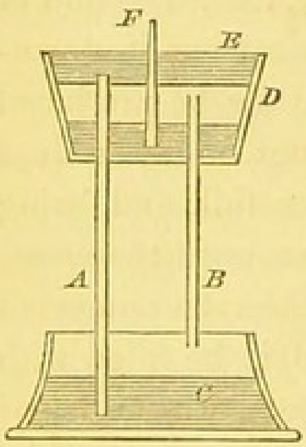


and escapes from the orifice, forming a little jet d'eau. This instrument is termed the *Wirtemberg syphon.*

The well-known scientific toy, called Tantalus's cup, consists of a glass vessel, in which the bent tube ABC is concealed. The long leg A passes out through the stem of the cup; on pouring water into this glass, it will hold it like any other vessel, until the horizontal branch B becomes filled, and then the water will escape through this syphon, until it falls below the level of the leg C. The mouth of a little image is often fixed at B, to represent the fabled Tantalus; and as soon as the fluid rises to his lips, it escapes through the syphon.



174. Another philosophic toy, illustrating some of the principles already laid down, is known under the name of Hiero's fountain, and consists of two vessels connected by the tubes AB, the tube B connecting the upper part of C with the upper part of D; whilst A passes air-tight through D, connecting the reservoir E with the bottom of the vessel C, a jet-tube passes through the reservoir E and extends to the lower part of D.—To use this apparatus, the vessel D and the reservoir E are nearly filled with water. The water placed in E falls down the tube A into C, forcing the air contained in the latter up B into D above the surface of the water in which it collects; more water falling down A, a larger quantity of air is forced through B into D; this eventually becomes so compressed as to act with great force on the water in D, and forces it to rise through the tube F, in the form of a jet d'eau. The mode in which this apparatus acts is, consequently, analogous to that of the compressed air fountain (155), differing only in the manner in which the compression of the included air is effected.



Almost every instrument by which water is raised to any elevation, acts more or less directly through the medium of atmospheric pressure. A comparatively small number depend on ordinary mechanical means for producing their effect, as the screw of Archimedes, the Persian wheel, the chain-pump, &c. whilst the rope-pump depends upon capillary attraction for its action.

175. The comparatively incompressible character of water is made available as a powerful mechanical power, in Bramah's hydraulic press: this celebrated and valuable piece of apparatus consists essentially of a very strong watertight box, the top consisting of a kind of piston, the upper end of which touches the substance to be submitted to pressure. The water-tight box, being filled with water by means of a small pump connected with it, the upper end of the piston presses forcibly against the substance exposed to its action. More water is then pumped into the already-filled vessel; and, in consequence of the law that no two bodies can occupy the same space at the same instant, something must yield; and as the piston is the most moveable part of the apparatus, it is pressed with an enormous force against the substance submitted to its action. Currents of water are used as mechanical agents, in moving machinery, by means of the well-known contrivances called water-wheels; and currents of air are made equally available, in turning the sails of the various forms of windmills. Indeed, in whatever light we regard the general and peculiar properties of both the elastic, or comparatively inelastic fluids, we cannot help being struck by the numerous ways in which they are so admirably fitted to supply the wants of man, and by which they are made available in adding to his various comforts, and ministering to his wants.

NOTE.

For further information on the contents of the last three chapters, the student should refer to the monographs in the Cyclopædias before referred to, and to the works of Dr. Gregory, Professor Young, Professor Playfair, Pouillet, Biot, &c. The following are references to Newton's Principia and Euler's Letters:

Chap. VI. Newton, bk. ii, sect. 5.
VII. Newton, bk. ii, prop. 22-3; Euler, vol. i. let. 9-15, and vol. ii. let. 22.
VIII. Newton, bk. ii, prop. 36, and sect. 9.

CHAPTER IX.

SOUND.

Tones and Noises, 176. *Diffusion of Sound*, 177—*checked unless a Conducting Medium be present*, 178. *Sounds vary with Condensation of Air*, 179. *Laws of Intensity of Sound*, 180.—*Circumstances modifying*, 181. *Communication of Sound*, 182—*Velocity of*, 184—*Calculation of Distances by*, 185—*Conducting Power of Bodies for*, 186. *Acoustic Shadow*, 187. *Sonorous Interference*, 188. *Passage of Sound through Mixed Media*, 189—*Reflection of*, 190. *Echo*, 191. *Reflection of Sound by Curved Surfaces*, 192—*Absorption of*, 193. *Transverse Vibrations*, 194. *Musical Notes*, 195—*Comparative View of Vibrations producing*, 196. *Discords and Concords*, 197. *Nodes*, 198. *Vibrations of fixed Rods*, 199—*of Columns of Air*, 200. *Acoustic Figures*, 201-203. *Musical Sounds evolved by heated Metals*, 204.

176. When the air, or any other elastic body, is made to assume a vibratory motion, consisting of a series of oscillatory movements, repeated with sufficient frequency, a *sound* is produced. When these vibrations take place in an uniform and regular manner as when a harp-string is struck by the finger, a perfect sound or *tone* is produced; but if the vibrations take place irregularly, or are suddenly checked by opposing causes, as in the explosion of a pistol, a *noise* alone ensues.

177. When these vibrations are excited with sufficient rapidity in an elastic body, their effects become transmitted by the excitations of fresh and similar movements in surrounding bodies and the air, extending on every side like the gradually widening circular ripples surrounding the spot

where a falling drop of rain disturbs the surface of a pool of water. These eventually ~~infringe~~ impinge upon the membrane of the tympanum or drum of the ear, and by causing it to vibrate, through the medium of the included air, or by means of the delicate chain of bones connecting them, or both, tremulous motions are excited in the fluid with which the labyrinth of the ear is filled; and which, acting on the auditory nerve, produce the sensation of sound.

178. Providing no substance intervene between the vibrating body and the ear, no sound is heard. If a bell be placed under the receiver of an air-pump (152), and the apparatus be shaken, the sound excited by the clapper striking the sides of the bell is distinctly heard. Let the air be exhausted from beneath the receiver, and the bell again agitated, the clapper will be seen to strike its sides, but no sound will be audible; in consequence of no elastic medium of sufficient density existing to convey the sonorous vibrations to the sides of the receiver.

179. Travellers, in ascending lofty mountains, have noticed the extraordinary diminution of the intensity of sound, in consequence of the rarefied state of the atmosphere at considerable elevations above the level surface of the earth (149). Saussure found that on the summit of Mont Blanc, the explosion of a pistol appeared no louder than that of a cracker, and conversely the intensity of sound increases, on increasing the density of the air surrounding the sonorous body; thus sounds, which are of ordinary pitch in the free air, acquire a painful degree of intensity if heard in a reservoir of condensed air, or in descending in a diving-bell, in which the air becomes condensed by the upward pressure of the water.

180. The intensity of sound, like that of attaction (12), diminishes in the inverse ratio of the squares of the distances of the sounding body. This law, however, applies with its full force only, when opposing currents of air, or other obstacles do not interfere; for the sound of a church-bell is inaudible, during a contrary wind, at the distance of a few

yards, whilst the sound of the cannonading at Waterloo was heard at Dover, and the noise of a sea-fight between the English and Dutch, in 1672, was heard at Shrewsbury, a distance of 200 miles. In these cases the intensity of the sound was no doubt preserved through these distances, by the presence of aerial currents, moving in the directions in which the sounds were heard.

181. From the researches of Dr. Derham, the intensity of sound is modified—A. By the direction and velocity of the wind. B. By varieties in barometric pressure. C. By changes in the temperature of the air. D. By its hygrometric state. E. By the original direction of the sound. F. By the nature of the surface over which the sound passes.

Sound is heard with great distinctness over a considerable space, in a frosty air undisturbed by winds or aerial currents. Lieutenant Forster, in the third Polar Expedition of Captain Parry, held a conversation with a man across the harbour of Port Bowen, a distance of one mile and a quarter.

182. When the air is in a state of sonorous vibration, it excites similar movements in bodies with which it is in contact, if they be properly situated. This may be shown by tuning two harp-strings in unison: on causing one to sound, the air surrounding it assumes a vibratory movement, and, impinging on the second string, causes that to vibrate, and emit a sound or tone. Instances have occurred of persons who, by modulating their voices, have excited vibration in glasses, so powerful as to overcome the aggregative attraction that held their particles together; and consequently to break them in pieces.

183. Waves on the surface of water, unless they differ very greatly in size, are capable of passing over each other without being destroyed. And in a similar manner, in the case of the waves of sound, or sonorous vibrations, excited by a crowded orchestra, an attentive ear can readily distinguish the sound of any particular instrument.

184. Sounds, in traversing given distances, are propagated

with equal rapidity, passing through spaces proportional to the times. The space passed through by sound of every degree of intensity, in a second of time, is generally stated to be 1142 feet. Sir John Herschel is induced to consider that, in dry air and freezing temperature, sound travels at the rate of 1090 feet, or rather more than 363 yards, in a second of time; and that, at 62° Fahr., it traverses 9000 feet in 8 seconds, $12\frac{3}{4}$ miles in a minute, or 765 miles in an hour, equal to a velocity of 1125 feet per second.

185. By knowing the velocity of sound per second, we can gain, in many instances, a close approximation to the knowledge of the distance of a vibrating body. As light travels with an enormous velocity as compared to sound, we can, by observing the number of seconds elapsing between the appearance of a flash of light and the instant when the sound produced simultaneously with such flash is heard, and multiplying this number by 1125, ascertain the distance in feet from the source of the explosion. The following are some examples of calculations of this kind.

(A). A flash of lightning is seen 12 seconds before the thunder is heard; what is the distance of the cloud where the explosion occurred?

$$8'' : 9000 \text{ ft.} :: 12'' : 13{,}500 \text{ ft.} = 4500 \text{ yards.}$$

(B). The flash of a cannon fired from a ship is seen 33 seconds before the report is heard; what is the distance of the vessel?

$$8'' : 9000 \text{ ft.} :: 33'' : 37{,}125 \text{ ft.} = 12{,}375 \text{ yards.}$$

186. Sound is not transmitted with equal facility through all media: thus, various gaseous mixtures assume sonorous vibrations with extreme difficulty. The sound of a bell under the receiver of hydrogen gas is, according to the experiments of Dr. Priestley and Sir John Leslie, scarcely louder than when placed under an exhausted receiver (178). When hydrogen is respired, the voice of the person undergoes a curious change, being rendered extremely feeble and raised in pitch, as we should expect it to be, from the lungs and

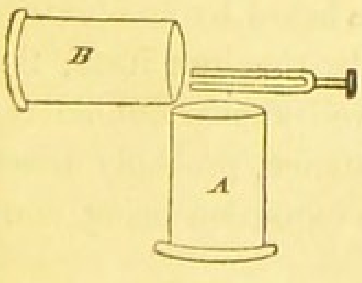
larynx being filled with a rarefied medium. Sound travels through different bodies with very different degrees of velocity. Thus, calling its velocity in air = 1, it travels in—

	VELOCITY.		
Distilled water	4·5	according to	Laplace.
Sea water	4·7		Do.
Tin	7·5		Chladni.
Silver	9·0		Do.
Cast iron	10		Biot.
Brass	10·5		Laplace.
Copper	12		Chladni.
Hammered iron	17		Do.
Wood	11 to 17		Do.

187. Sounds excited in air are indistinctly heard by a person immersed in water; but if excited in that fluid, they are coveyed to a considerable distance with facility. M. Colladon heard the sound of a bell struck under water across the whole breadth of the lake of Geneva, a distance of nine miles; this sound appeared to pass through the water with a velocity of 4708 feet per second.

Sounds excited in air are distinctly audible to persons cut off from rectilinear communication with the body by a projecting wall, although with some diminution of intensity. In water, however, M. Colladon found that the presence of a wall or projection, interfering between the ear and sounding body, nearly rendered the sound inaudible, as though a sort of "*acoustic shadow*" had been produced by the wall.

188. Two sets of sonorous vibrations of equal intensity, and encountering each other in opposite phases of vibration, will interfere, and become mutually checked; and thus silence be produced by the conflict of two sounds.



This may be shown by vibrating a common tuning-fork or diapason, and holding it over the mouth of a cylindrical glass vessel, A; the air contained in which will assume sonorous vibrations, and a *tone* will be produced. Then hold a second glass cylinder in the direction shown by the figure B, at right angles to A, and immediately the musical tone previously heard will cease; withdraw B, the tone reappears; approach it, and it once more disappears, and so on. These curious phenomena arise from the interference of the sonorous vibrations excited in A and B.

189. The passage of sound through heterogeneous media composed of substances of different degrees of elasticity, is effected with difficulty; for in passing from a less to a more elastic portion, sonorous waves of different intensities are excited; which, partly being reflected (190), and partly from mutual interference (188), become broken up, as it were, into myriads of secondary vibrations; and thus, the sound, which eventually reaches the ear, will be not only of less intensity, but of different tone from the true one. If some portions of a mixed medium be capable of conducting sound better than others, some vibrations will reach the ear before the others, and a confused false sound will alone be heard. We have an example of these facts in a glass vessel filled with carbonic acid; this, when struck, instead of emitting the full tone, proper to it, will merely produce an irregular flat sound: here the medium in which the vessel is immersed, the air, is of very different density and conducting power from that with which the glass is filled, and accordingly, vibrations of different intensities are excited, which, probably, by their interference (188) deaden the proper tone of the glass vessel. The comparative conducting power of different media for sound was well illustrated by an experiment of Biot's. This philosopher fixed a bell at the end of a long iron tube; on striking it, two consecutive sounds were heard by an observer at the opposite end, one conducted by the iron itself, the other by the air in its interior. The well-known double report of a fowling-piece, fired at a distance, probably arises from a similar cause, the sound of the explosion being con-

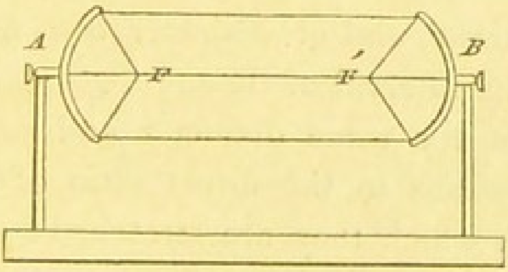
ducted to the ear, unequally by the air, and the masses of vapour floating in it.

190. Sonorous vibrations, on impinging on a plane surface, are reflected from it in such a manner, that the angles of incidence and reflection are equal, in the same manner as in the case of collision of an elastic body against a plane surface (46): the rapidity and intensity of the sound continuing the same after, as before reflection.

191. When a sound is reflected from a plane, and reaches the ear after a certain interval, an *echo* is produced; for this to be perfect, the observer must be at a certain distance from the reflecting plane; and if this distance be 54·1 feet, or a little more, he will hear repeated the last syllable of the words he uttered, for a perfect echo ensues after a lapse of 0·1 second; and the syllable will be repeated once or several times, according to the number of reflecting surfaces presented by the body against which the sound impinges. The reflecting plane must be at a greater distance to afford polysyllabic echoes. At Woodstock is one of this kind, repeating seventeen to twenty syllables.

When sound is reflected between parallel planes, at a proper distance from each other, multiplied echoes are produced, repeating syllables as many as forty times.

192. Sound is reflected by curved surfaces in the same manner as light and heat. If AB be two mirrors composed



of any hard polished substance, and in the focus of A at F, a low sound, as a whisper, be uttered; it will be reflected to A, from thence, in the direction of a series of lines parallel to those drawn in the figure, to B, from which it will reach the focus F′, and be distinctly audible to an observer there situated. In a similar manner, any sound in an elliptic chamber, uttered in one of the foci of the ellipse, will be audible to an observer placed in the other focus, whilst persons placed midway will not be able to hear it.

193. If the substance against which the sound impinges be soft and yielding, it will be much diminished in intensity; thus, whilst voices are heard in a remarkably sonorous manner in lofty apartments with hard polished walls, they almost cease to be audible in chambers hung with tapestry, from the sonorous vibrations becoming checked or absorbed, on impinging against this soft and yielding material.

194. When cords are made to vibrate in a transverse direction, as by drawing a bow across a violin string, or by touching a harp-string with the fingers, the following phenomena are observed:

(A.) Cords of the same diameter, and equally stretched, have the number of vibrations, in a given time, in the inverse ratio of their lengths. Thus, a cord, performing thirty-two vibrations in a second, will, if shortened to one half, produce sixty-four, and if to one third, ninety-six vibrations, in the same time.

(B.) Cords of the same length and degree of tension, have the number of their vibrations in the inverse ratio of their diameters: ex. gr., a cord of diameter three, will produce thirty-two vibrations in a given time, of diameter two, sixty-four vibrations, and of diameter one, ninety-six vibrations, in the same interval of time.

(C.) Cords of the same diameter and length have their number of vibrations in the direct ratio of the squares of the weights with which they are stretched: ex. gr., a harp-string stretched with a weight of one, will produce a certain number of vibrations; with a weight of two, will produce four times as many; and with one of three, nine times as many, in the same space of time.

195. When a sound is produced by vibrations sufficiently regular to constitute a musical tone (176), each being produced by a certain and definite number of vibrations, it is termed a *note;* and to distinguish one from the other, a series of terms are applied to them. These, in this country, are taken from the alphabet, the first seven letters being used to designate particular notes. On the continent, the seven syllables, *ut*, *re*, *mi*, *fa*, *sol*, *la*, *si*, are usually preferred. These *notes* constitute what is termed, the *Diatonic* scale or *gamut*. A note is said to be sharper than another when it is produced by a larger number, and to be graver or baser than another, when by a smaller number of vibrations in a given time. The gravest audible sound is produced by about thirty-two, and the sharpest by about 15,000 vibrations in a second. A collection of eight consecutive notes is termed an octave, and one octave is said to be higher or lower than another, when the notes it contains are produced by a greater or smaller number of vibrations in a given space of time.

196. A note of any octave is produced by a certain number of vibrations, which are twice as numerous as in the corresponding note of the next lower, and are half as numerous as in the corresponding note of the next higher octave.

In the following table, the continental names of the notes, their English synonyms, the comparative lengths of the strings, and number of vibrations producing them, as well as the absolute number of vibrations in a second performed by the strings to produce a particular note, are at once seen. The figures in the last column must be considered as only approximations to the true numbers. The octave here taken as an example, is the fourth from the base of the piano :—

Names of Notes.		Comparative		Number of vibrations in a second.
Continental.	English.	length of string.	number of vibrations.	
ut	C	1	1	258
re	D	$\frac{8}{9}$	$\frac{9}{8}$	290
mi	E	$\frac{4}{5}$	$\frac{5}{4}$	322
fa	F	$\frac{3}{4}$	$\frac{4}{3}$	344
sol	G	$\frac{2}{3}$	$\frac{3}{2}$	387
la	A	$\frac{3}{5}$	$\frac{5}{3}$	430
si	B	$\frac{8}{15}$	$\frac{15}{8}$	483
ut	C	$\frac{1}{2}$	2	516

197. The perception of a simple musical tone has been aptly compared by Euler,* to a series of dots equidistant from each other, thus, ...

If the intervals between these dots be greater or smaller, the tone produced will be lower or higher (195). It can scarcely be doubted that the perception of a single tone is analogous to the sight of such a set of equidistant dots; thus enabling us to represent to the eye, what the ear perceives on hearing sound. If the distances between the dots be not equal, or if they be irregularly scattered, they would represent a confused noise, inconsistent with harmony. When two tones, each produced by the same number of vibrations, strike the ear simultaneously; they appear to blend, forming an *unison*; which may be represented by two lines of equidistant dots, thus ::::::::::::

When the difference between the number of vibrations producing any note is in a simple ratio, so that the ear readily discovers the relation existing between them, a *concord* is produced. But if from the absence of this simple ratio, it be difficult or impossible, to discover this relation, a *discord* is

* Letters to a German Princess, vol. i. let. 4.

said to exist. The following are some of the most important concords.

(A.) The octave, represented by two, because the sharper note is generated by twice the number of vibrations that the graver one is, corresponding to the intervals of the two C's or *uts* : this concord may be represented by ·:·:·:·:·:·: the upper line representing the sharp and the lower the grave note.

(B.) The fifth, $\frac{3}{2}$ the sharp note being produced by three vibrations whilst the base is produced by two in the same time, corresponding to the interval of C to G, or *ut* and *sol*: this concord may be represented by ::·::·::·::·::·::

(C.) The fourth, or $\frac{4}{3}$, the sharp sound produced by four and the grave by three vibrations in a given time : this corresponds to the interval of C to F, or *ut* to *fa*, and may be represented by :::·:::·:::·

(D.) The major third, or $\frac{5}{4}$, corresponding to the interval C E, or *ut* to *mi* : this concord may be represented by ::::·::::·

(E.) The minor third, or $\frac{6}{5}$, is the interval E to G, or *mi* to *sol* ; represented by :::::·:::::·

198. If, when a string is vibrating, it be suddenly checked by touching it in the centre, its two halves will vibrate twice as rapidly as the entire string, each producing the same note of the next higher octave. This sometimes occurs spontaneously, producing a series of *harmonic sounds* ; it is readily produced in the strings of the harp and violoncello. When this phenomenon occurs, the point midway between the two ends of the string is at rest, whilst the rest is rapidly vibrating ; any number of these points may exist in the same string : they are termed *nodi*. At these points the string never leaves the axis, for let the dotted line AB represent the

direction of a stretched string, and, after it has been made to vibrate, it be touched with the finger at C, the two halves CB, CA, will begin to vibrate twice as rapidly as the entire string

AB did, but in contrary directions, each end pulling equally from C will cause this point or *node*, to remain at rest and in the direction of the long axis of the string.

199. When rods of metal, fixed at one end, be made to vibrate, they produce sonorous vibrations in the inverse ratio of the squares of their lengths, and in the direct ratio of their diameters. These, like strings, may vibrate entire, or divided into nodi.

200. When sonorous vibrations are excited by blowing into tubes, the sharpest notes are, cæteris paribus, excited by the shortest tubes. Sounds thus excited, are produced by the alternate condensations and expansions of the different layers contained in the column of air in the tube. The following are some of the more important facts connected with the relation between the sound evolved, and the length, and open or closed extremities of the tubes employed.

(A.) In cylindric tubes, *closed at one end,* the vibrations are in the inverse ratio of the length of the tube.

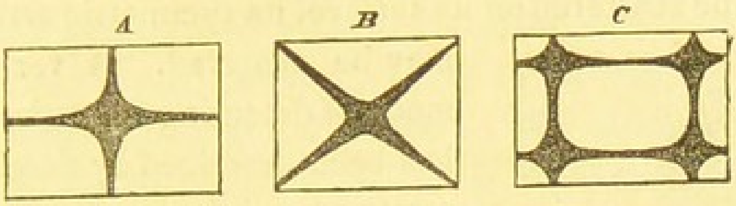
(B.) In a cylindric tube, *open at both ends,* the sound is the same as that produced by a cylindric tube closed at one end, and one half its length.

(C.) In a cylindric tube, *closed at both ends,* the sound is the same as in a tube closed at one end, and of one half its length.

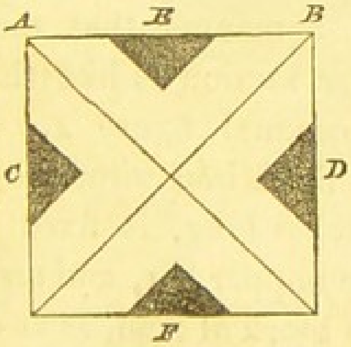
(D.) Nodi, or points of rest, in the included column of air, are observed in the case of vibrations of this kind as in vibrating cords (198), or rods (199).

201. Vibrations are readily excited in elastic plates by friction or by striking them, and sounds are evolved: the plates dividing themselves into vibrating portions, separated by nodi or points of rest, arranged in lines: these are beautifully shown by scattering sand on the plates, and vibrating them; the sand will assume a curious rapid movement, and be thrown off the vibrating portions, upon the nodi or lines of rest. If a square plate of glass be held in the centre by a vice, sand scattered over its surface, and the bow of a violin drawn rapidly

across it close to one of its angles, the sand will be thrown into the position shown in A. If the bow be applied to the middle of one of the sides, the sand will be arranged as in B. If the plate be held near one of its angles and the bow applied as before, the sand will be arranged as in C.

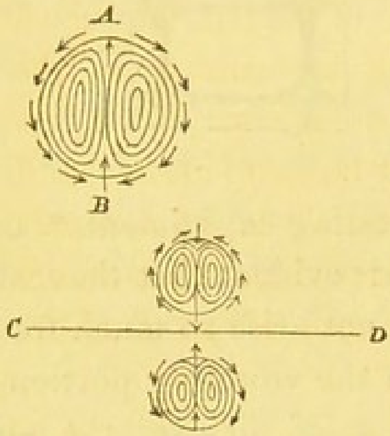


202. From a series of highly interesting experiments* on this subject, by Dr. Faraday, it appears evident that the scattering of sand on the nodal lines does not arise so much from its being, as it were, jerked off from the vibrating portions, as from the vibrations exciting currents of air over the agitated portions, which, entangling the powder scattered on the plate, carries it to the lines of rest or *nodal lines*. If the powder be a very light one, as *lycopodium*, instead of sand, this will be caught up by the aerial currents, and will collect chiefly on the most agitated portions of the plate, and appear animated with a curious vortex-like motion. If the plate be vibrated in very rarefied air, the lycopodium will be collected on the nodal lines, like the sand when vibrated in ordinary states of atmospheric pressure; and if covered with sand, and made to vibrate in water, the sand will be collected chiefly on the most agitated portion of the plate. Thus, the lines AB represent the position of the sand when the plate is vibrated in air, and of the lycopodium when in vacuo, and the triangles ECDF, the parts or *inter-nodal spaces* wherete sand is collected when the plate is vibrated in water, and the lycopodium when in air.

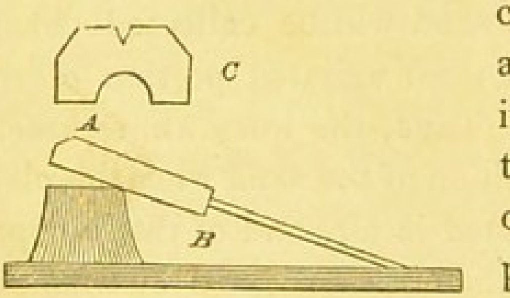


* Phil. Trans. 1831.

203. These acoustic figures may be well exhibited by stretching a piece of bladder over the mouth of a funnel, and passing a horse-hair, retained by a knot, through its centre; or drawing the hair through the fingers, previously rubbed over with resin, the membrane will be made to vibrate, and if the sand be scattered on its surface, its symmetric arrangement may be observed. A very delicate mode of detecting acoustic vibrations has been described by Strehlke:* he scatters some lycopodium on water, so as to cover its surface with the thinnest possible layer, which is best effected by agitating the fluid in a box, the inside of which has been rubbed over with the powder. On placing a drop of this on a vibrating body, the particles of lycopodium begin to revolve in the water, dividing into two or more currents, if the sonorous vibrations be intense, as shown at AB. If a drop be placed on each side of a nodal line, or line of rest (198), CD, these intestine motions occur, but in opposite directions.



204. The evolution of musical sounds during the cooling of heated metals, observed by Mr. Trevelyan and others, are extremely curious, these are best observed by using bars of copper five inches long and about half an inch thick, grooved in such a manner that their transverse section is like that of the marginal figure A. A piece of thick iron-wire, about eight inches long, is fixed in one end for a handle. On heating the copper bar, and resting its convex portion on the edge of a block of lead, as at B, it will begin to vibrate strongly; and soon afterwards evolve



* Poggendorff, Annalen 40, p. 146.

loud musical sounds, usually beginning like the drone of the bagpipes, and rising to a loud plaintive swell, like that of the Æolian harp, and then falling in the most fitful manner. These wild and irregular sounds continue until the temperature of the block of lead and copper-bar are nearly equalized. These sounds are evolved with the greatest shrillness when a small channel is filed out in the back of the bar, as shown in A, or a similar channel excavated in the surface of the leaden block on which it rests. It is necessary that the surfaces of the metals employed should be quite clean; and that their powers of conducting heat should be as different as possible; hence, copper and lead succeed the best, as the conducting power of the former for caloric is 398, and of the latter 179·6, according to Despretz.

NOTE.

To no work can the student refer with so much advantage as to Sir John Herschel's Monograph on Sound, in the Cyclopædia Metropolitana: here he will find all that is valuable on this subject, and nothing superfluous. The following are the references to Newton and Euler:

Newton, bk. ii, sect. 8.
Euler, vol. i, letters 3 to 8.

SECTION II.

PHYSICS OF IMPONDERABLE MATTER.

Magnetism, Chapter X. Ordinary Electricity, Chapter XI.—XIII. Atmospheric Electricity, Chapter XIV. Voltaic Electricity, Chapter XV. Electro-dynamics, Chapter XVI. Electro-dynamic Induction, Chapter XVII. Thermo-electricity, Chapter XVIII. Organic Electricity, Chapter XIX. Luminous Undulations of Imponderable Matter or Light—Unpolarised Light, Chapter XX.—XXII. Polarised Light, Chapter XXIII.—XXIV. Optical Instruments, Chapter XXV.

CHAPTER X.

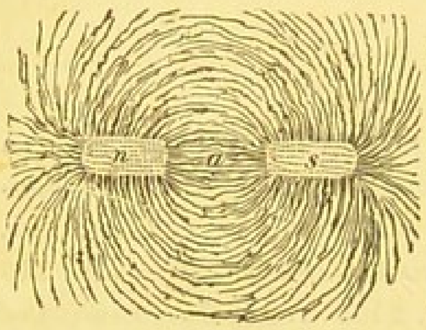
MAGNETISM.

205. The property possessed by certain ferruginous ores, of attracting pieces of iron, has been long known; and the ores themselves have been termed *magnets* from Magnesia, a country of Lydia, in which they were stated by the ancients to abound. All the phenomena possessed by such magnets, including their action on iron, cobalt, and nickel, the only metals which, in a pure state, appear to obey their attractive influence, have been collected, and the important science of *magnetism* founded upon them.

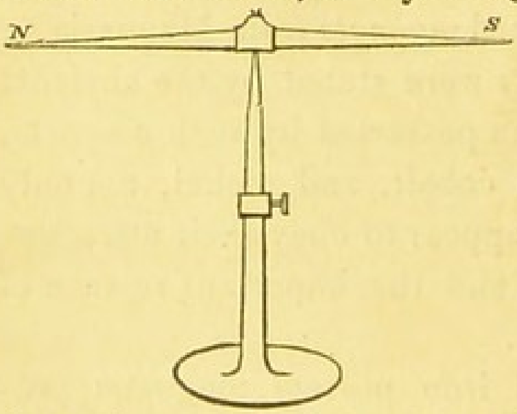
206. Not only do ores of iron possess magnetic properties, but masses of that metal which have been placed in contact with them, or have been submitted to the effects of certain mechanical actions, generally present the phenomena of magnetism. The magnetic ores constituting what are termed *natural*; and the latter, *artificial* magnets. In ex-

amining the phenomena they present, it matters not which we use; magnetic bars of iron, however, being generally preferred on account of their convenient form.

207. If a magnet be dipped in iron filings, it will attract, and cause them to adhere to its surface, but unequally in different parts; being collected in abundance at the ends, and nearly absent from the intermediate portions. This is best seen by placing a sheet of paste-board over a magnetic bar, scattering iron filings on its surface, and then tapping the paste-board lightly with a stick; the filings will arrange themselves in lines diverging from the ends of the magnet in curves, the centre *a* being nearly free from them. The terminations of the magnet, in which the magnetic action appears to be concentrated, are termed *poles*. The greatest intensity of action is not found to be exactly at the extremities of the magnet, but at a little distance from them, as the points *ns*, representing centres, from which the diverging curves of iron-filings appear to radiate.



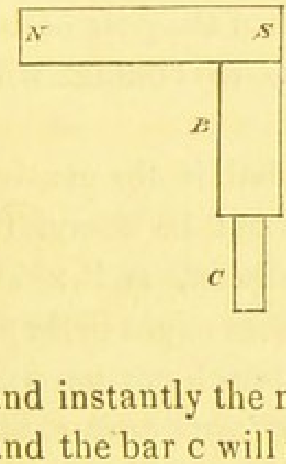
208. Let a magnetic bar be suspended by a thread tied round its centre, or by being fixed on a pivot as NS, so as to be free to move round a vertical axis; and it will be found to assume, after a few oscillations, a constant position. If it be moved from this position, the bar will return to it as soon as the coercing force is removed. One of the poles (207) of the bar will be found to point constantly towards the north, and the other towards the south. The former N is, in common language, called the north, and the latter S the south, pole of the magnetic bar, (212, 214).



209. Approach towards the *north* pole of a magnet,

placed on a pivot (208), the *south* pole of a second magnet held in the hand; immediately the former will move towards the latter, being attracted by it. If, then, the *north* pole of the magnet presented to the needle, be substituted for the *south*, the *north* pole of the moveable magnet will fly round, to attain the greatest distance possible from it, repulsion having taken place. Hence we learn that *poles of the same name repel, and those of different names attract each other.* That the attraction, or repulsion is mutual, may be proved by using two magnets on pivots instead of but one.

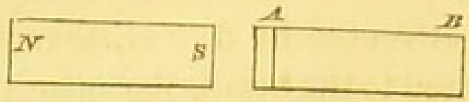
210. When a piece of iron is attracted by a magnet, it assumes magnetic properties. Present a piece of soft iron



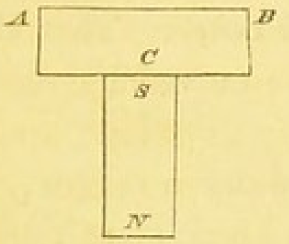
B, towards the south pole (208) of a magnetic bar NS; it instantly becomes attracted: and if a second bar, C, be presented to B, it will attract it almost as strongly as it is *itself* attracted by the magnetic bar; proving that B assumes magnetic properties under the influence of the bar NS: gradually strike NS off B, and instantly the magnetic properties of the latter will vanish, and the bar C will fall from it. The influence exerted by NS on B, is termed *induction*, because it *induces* magnetic properties in that bar; retaining them in it, whilst they remain in approximation. If the end of B be dipped in iron filings whilst in contact with NS, they will adhere to it and arrange themselves in curved lines (207). And in the experiment before mentioned (207), in which iron filings became arranged in curved lines, under the influence of a magnetic bar placed beneath them; the filings became magnetic by *induction*, each single one acting on its neighbour, like a little magnet on a pivot (208), attracting or repelling it according to circumstances.

211. Whenever the pole of a magnet induces magnetism in a bar of iron, the end of the latter nearest either pole will acquire properties of the *opposite* kind to it. Then if the iron bar AB be brought near NS, it will become magnetic by induction

(210), the end A becoming the north, and B the south pole,



if the end S of the magnet were a *south*, and N a *north* pole.



If the magnet SN be brought in contact with the middle of a bar of iron AB, the centre C will become a north pole, and the ends AB both south poles. And if the pole of a magnet be placed in the centre of a circular piece of sheet iron, the whole circumference will assume magnetic properties of the same kind as that of the pole of the magnet, whilst the centre with which it is in contact will assume an opposite polarity.

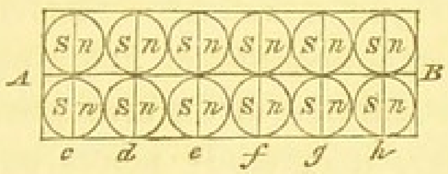
211*. If a magnetic bar NS, be broken in half in the centre,

the half S will not be found to possess all southern, and N all northern polarity, as might perhaps be expected, but each portion will become a perfect magnet, each of the fractured ends exhibiting a polar state, as perfect as the entire magnet; the fractured [end *s*,' becoming a south and *n* a north pole; although at this middle point where *s*' and *n*' join, no magnetism could, before breaking it, be detected.

212. From these and similar experiments, a tolerably satisfactory theory of magnetism has been framed, which, if not correct, is certainly very convenient, as affording a key to all the ordinary magnetic phenomena, and may be admitted as at least a conventional hypothesis. According to this, two distinct magnetic fluids exist, one consisting of *austral*, the other of *boreal* magnetism, and under the influence of either, in a *free* state, the bar of iron or other metal, will point to the north or south poles of the earth, according to circumstances. In ordinary iron, these fluids exist in a

combined state, and therefore are perfectly latent, the metal appearing to be destitute of magnetism. These fluids exist in a certain proportion united to each molecule, or atom of the metal, and from which they *can never be disunited;* the only change which they are capable of undergoing being their decomposition into the separate fluids, one of which in a permanent magnet, is always collected on one, and the other on the opposite side of each particle or molecule of metal.

213. This theory explains the curious circumstances of a magnet possessing no attractive influence in its centre, and of its magnetism being apparently concentrated in the poles; for



if AB represent a bar magnet, consisting of two rows of spherical molecules; the *austral* fluid will all be collected on the sides of the atoms nearest B, and the *boreal* fluid on those nearest A. Then the effects of the *austral* fluid collected on one side of the molecule *c*, will be completely counteracted by the *boreal* fluid on the opposite side of D, the *austral* of this by the *boreal* of *e*, and so on, until we come to the last molecule *h*, whose *austral* side, having no other atom to oppose its action, will exert the ordinary attractive and repulsive effects of free magnetism. In the same manner the *boreal* side of *c*, will exhibit the phenomena of free magnetism; the particles in the second row will also be similarly arranged and exhibit similar phenomena. Thus we see that the central portions of a bar magnet *cannot* exhibit evidence of free magnetism, because the magnetic fluid in one particle is held virtually neutralised, or disguised, by that next to it and so on.

An extension of this mode of reasoning will show why a steel ring may be converted into a magnet, by passing it over the pole of a permanent magnet, without its exerting any attractive influence on iron, or exhibiting any other phenomena characteristic of free magnetism; for here every portion of the ring being *continuous*, the separated fluid on the side of every atom is held *disguised* by the free fluid of the opposite kind, on the opposed side of the next atom in the series. On breaking such a ring in half, the terminations of the fractured portions will be found to be energetic magnetic poles, from the portions which disguised their polar state being removed. And thus every fragment of a fractured bar is a perfect magnet, a fact so interesting and extraordinary that the Abbe Hauy has wittily termed magnets *les polypes du regne mineral.** A German philosopher Eschenmaier,† has proposed the following formula as exhibiting an hypothetical view of the arrangement of magnetism in a magnetic bar; it certainly points out the absence of polar properties in the centre, end their gradual increase as we approach the extremities of the bar:

$$M^n \text{———} M^3\ M^2\ M^1\ M^0\ M^{-1}\ M^{-2}\ M^{-3} \text{———} M^{-n}$$

the letter M, with the positive exponents 1, 2, 3, &c. representing one (as the *austral*) fluid, and with the negative exponents— 1—,2,—3, the other or *boreal* fluid.

The phenomenon of induction admits of a similar explanation; for if A in the above figure be the *austral* pole, (or that which, if freely suspended, would *point to the north*,) of a large magnet, placed nearly in contact with a bar of soft iron *c h* the combined magnetism will be decomposed, its *boreal* fluid will be attracted to the sides of the atoms of iron nearest A, its *austral* fluid repelled to the opposite sides, and the bar of iron will become a magnet. If the magnet A be then removed, the separated magnetic fluids recombine, and the bar of iron is left free from magnetic properties; but if the bar be of hard iron or steel, the inductive action (210) of

* Traité de Physique. ii. p. 89.

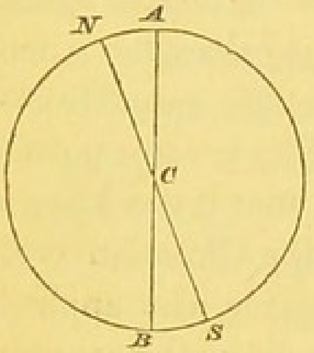
† Gesetze magnetisch. Erscheinung. *Tubingen*, 1798.

the magnet A, although far less powerful, is considerably more permanent, for the magnetic fluids remain separated after the removal of the magnet which induced their separation, or decomposition. Indeed, it would appear that the closer texture, and greater density of hard iron, or steel oppose themselves mechanically to the free and ready movement of the imponderable fluids imprisoned in the interspaces existing between their molecules.

214. A magnetic bar properly balanced upon a pivot is generally termed a *needle*, and constitutes the active agent in the well-known mariner's compass; guiding the sailor when all other indications of his course fail him. This valuable instrument was used in Europe in 1180, according to some poems of Guy of Provence; it is tolerably certain that it was known to the Chinese nearly 1000 years before the Christian era. Marco Paolo was the first European navigator who applied the compass needle to the practical, and important purposes for which it is now constantly used, in his return to Europe from the East Indies in 1295. This important property of a magnetic needle pointing towards the north and south poles of the earth, has been variously accounted for; thus Cardan has supposed that a star lodged in the constellation of Ursa Major attracts the needle, whilst others with more probability have supposed the earth to be, or to contain an enormous magnet, whose poles nearly correspond to the geographical poles of the globe. If this be admitted, we must suppose that a large collection of free *boreal* fluid is laid up in the northern, and of *austral* in the southern hemisphere. And in this case, that the pole of the magnetic needle which points to the north, contains free southern, or *austral* magnetism; because poles of the same name repel each other (209), and accordingly that pole of the needle which points towards the north has been termed *austral*, and that towards the southern *boreal*.

Some philosophers, as Berzelius, have preferred the terms *negative* and *positive* fluids, to austral and boreal. It signifies but little which are adopted, provided their conventional meanings are well understood, and as the terms *austral* and *boreal* are almost universally used, I have preferred them. It is only necessary to recollect, in reference to a magnetic bar, that *boreal, southern,* and *positive,* all refer to that pole which would point towards the south; and *austral, northern,* and *negative,* all refer to that which would, if freely suspended, point towards the north.

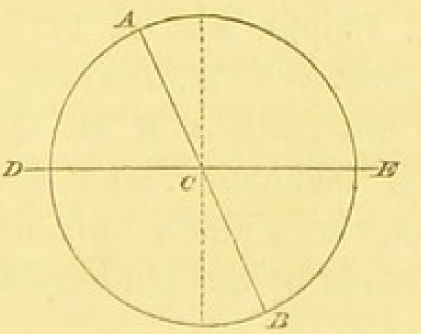
215. The magnetic needle does not point exactly north and south; and consequently the magnetic meridian, or place bisecting the earth in the direction of the needle, does not coincide with the geographic meridian. The magnetic meridian is not constant, sometimes being on the east, and sometimes on the west of the geographic meridian; this difference is termed the magnetic *declination,* or more commonly magnetic *variation.* Thus, if AB represent the geographic meridian, NS will represent the direction assumed by a compass-needle, or magnetic meridian, and the angle NCA is termed the angle of declination, or variation. In certain portions of the earth the magnetic and geographic meridians appear to coincide, as in some parts of North America, the north-eastern point of South America, western part of Australia, &c. These places are connected by an imaginary irregular curved line, termed the *line of no variation.* This line appears to move progressively over the surface of the globe, it passed over London in 1660, in which year the needle there pointed exactly to the north, and in 1663 it passed over Paris. At London the needle at present points about 24° west of the true north pole, the maximum variation having been attained in 1818, when it amounted to 24°·30′. The following table presents a view of the variations of the magnetic needle in London and Paris during several years:



Declination or Variation of the Needle at LONDON.			PARIS.		
Year.	Variation	Direction	Year.	Variation	Direction
1580	11·16	E.	1580	11·30	E.
1634	4·6	E.	1618	8·0	E.
1660	0·0	—	1663	0·0	—
1670	2·30	W.	1678	1·30	W.
1690	6.0	W.	1700	8·10	W.
1720	14·17	W.	1767	19·16	W.
1740	17·0	W.	1780	19·55	W.
1750	17·48	W.	1785	22·0	W.
1770	21·9	W.	1805	22·5	W.
1780	23·17	W.	1813	22·28	W.
1790	23·39	W.	1817	22·19	W.
1800	24·3	W.	1822	22·11	W.
1810	24·11	W.	1825	22·12	W.
1818	24·30	W.	1832	22·3	W.
			1835	22·4	W.

The greatest variations ever observed, were by the Chev. de Langle, between Greenland and Labrador, amounting to 45° west; and by Capt. Cook, in 60° s. lat. and 92°·35′ long., when the variation amounted to 43°· 6′, east of the geographic meridian.

216. The magnetic needle, if suspended on an horizontal axis at its centre of gravity, does not remain horizontal; its *austral* end in our hemisphere dipping considerably, and appearing the heaviest; and in the southern hemisphere the opposite pole inclines: this is termed the dip or inclination of the needle, and a needle thus suspended is termed a *dipping-needle*. At the equator, this dip *nearly* disappears, as there both poles are equidistant from the geographic poles of the earth, although it does not disappear entirely at the geographic equator, as this differs from the magnetic equator,



or the situation where the needle is horizontal, in a similar manner as the meridians differ (215). Let AB be a needle balanced on its horizontal axis C; in England then, instead of remaining horizontally, as DE, it dips or inclines towards the north, its austral pole forming an angle CBE of nearly 70_0 with the horizontal line DE.

The magnetic equator is tolerably regular for a part of its course, and may be represented by a part of a large circle inclined at an angle of 12° or 13° to the geographic equator. In the southern hemisphere, however, especially between the Sandwich and Friendly Islands, this line presents numerous irregular and sinuous curves like the magnetic meridian. The inclination or dip of the needle undergoes periodic variations, but by no means to so great an extent as the declination (215).

Inclination of the Needle at			
LONDON.		PARIS.	
Year.	Angle of Declination.	Year.	Angle of Declination
1680 . .	. 73°·30′	1798 . .	. 69°·51′
1723 . .	. 74 ·42	1810 . .	. 68 ·50
1773 . .	. 72 ·19	1818 . .	. 68 ·35
1786 . .	. 72 ·8	1824 . .	. 68 · 7
1790 · .	. 71 ·53	1825 . .	. 68 · 0
1800 . .	. 70 ·35	1826 . .	. 68 · 0
1818 . .	. 70 ·34	1829 . .	. 67 ·41
1828 . .	. 69 ·47	1831 . .	. 67 ·40
1830 . .	. 69 ·38	1835 . .	. 67 ·24

The greatest *inclinations* of the needle ever observed, were by Capt. Cook, who, in 60°40′ s. lat. observed it to be 43°45′; and Capt. Phipps, who in 1773, in 79°44′ N. lat. found it to be as great as 82°9′, or nearly vertical.

217. From the observations of M. Quetelet, it appears that the angles of inclination, and declination seem in Europe to be undergoing a gradual diminution; these angles at Brussels, were found by this philosopher to be of the following values:

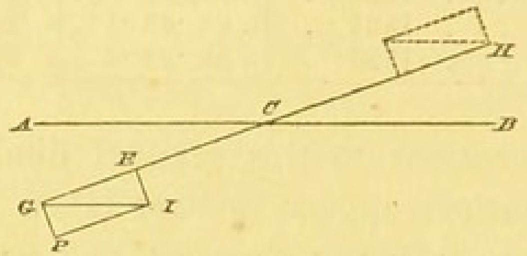
Month.	Year.	Inclination.	Declination.
October .	. 1827 .	. 68°·56′·5″ .	. 22°·28′·8″
March .	1830 .	. 68 ·52 ·6 .	· 22 ·25 ·3
March .	. 1832 .	. 68 ·49 ·1 .	. 22 ·19 ·0
March .	. 1833 .	. 68 ·42 ·8 .	. 22 ·13 ·4
April ·	. 1834 .	. 68 ·38 ·4 .	. 22 ·15 ·2
March .	. 1835 .	. 68 ·35 ·0 .	. 22 · 6 ·7
March .	. 1836 .	. 68 ·32 ·2 .	. 22 · 7 ·6
March .	. 1837 .	. 68 ·28 ·8 .	. 22 · 4 ·3
March .	. 1838 .	. 68 ·26 ·1 .	. 22 · 3 ·7
March ·	. 1839 .	. 68 ·22 ·4 .	. 21 ·53 ·6

The only exceptions to this gradual diminution of the angle of *declination*, appear to have taken place in 1834, when an increase 1°58′ was observed, and again in 1836.

218. In addition to these, the compass-needle, like the barometer (148), undergoes daily and even horary variations. The diurnal variations of the needle are such, that its *austral* pole moves towards the west from sunrise to about an hour after noon, when it retrogrades towards the east, until eight o'clock in the evening, after which, it remains nearly stationary, until sunrise. The amplitude of these variations differs considerably in different parts of the earth, and even in different months of the year; in London it attains, in June and July, 19′·6″, and in December, 7′·6″. In Paris, its maximum is as in London in June and July, and varies from 13′ to 16′, falling in December to 8′ or 10′. In the northern parts of Europe and America the diurnal variations are more considerable, but less regular; and under the magnetic equator (216) they vanish entirely; and on the south of the equator they reappear in an inverted order, the variations being eastward instead of westward.

219. Besides these *regular* variations, there are others connected with certain meteoric and electric phenomena, the appearance of the aurora borealis, an eruption of a volcano, a flash of lightning, all exert perturbing effects upon the magnetic needle; the latter indeed has occasionally reversed its polarity, or even destroyed it entirely.

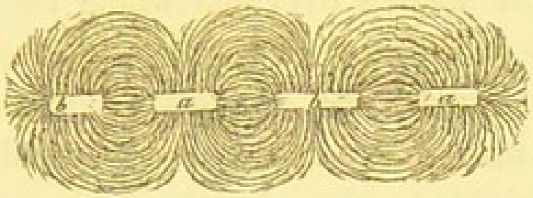
220. The actions exercised by the earth upon a magnetic needle is not a directly *attractive* but rather a *directive* force, which may be represented by two equal, parallel, and opposed forces: this may be readily understood by admitting the distance of the magnetic poles of the globe to be almost infinite with regard to the needle, and thus permit their influence to be exerted on the needle in parallel lines. For



if a magnetic needle AB, be made to assume the direction GH by the application of any force, the resultant of all the forces which act obliquely on G, to move it towards A, may be represented by GI, parallel to AC. But this force may be decomposed (50) into two others, one IP parallel, and another, IE, perpendicular to GC. On completing the parallelogram GEIP, the line GP will represent that part of the force GI, which is effective and active in moving G towards A. At the other end H of the needle, a similar application of the parellelogram of force will also apply; the forces acting on the opposite ends of the needle in opposed directions will tend to produce similar effects, and to *direct* the needle GH into the direction of the magnetic meridian AB. This *directive* action on the needle is always *equal to the sine of the angle* made by it, with the magnetic meridian. That the action of the earth is not in effect simply attractive or repulsive, like that of a small magnet, is proved by placing a magnetic needle fixed in a piece of cork on the surface of water, it will place itself in the magnetic meridian, but will not move *towards* either of the poles of the earth.

221. Occasionally a magnetic bar will be met with, in which magnetic properties are developed, not only at its poles, but in certain intermediate positions : this arises from

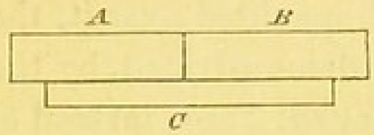
an irregular distribution of the two fluids, and is generally connected with some peculiarity in the structure of the bar, or in the mode in which the decomposition of its latent and

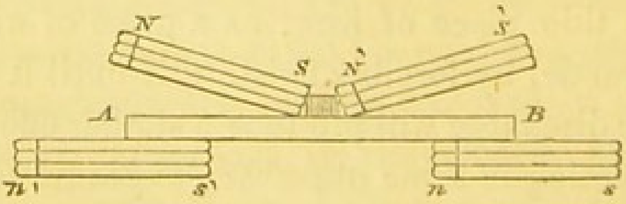


combined magnetism is effected. In such a bar, if placed beneath a sheet of pasteboard, and iron filings sifted over it, the existence of its several poles will be demonstrated by the manner in which the filings become arranged. Thus, instead of forming two series of curves (207), as many become developed as there are poles in the bar, these intermediate portions are called *consecutive poles.* Thus, in the above figure, *ba* are the terminal, and *ab* the consecutive poles.

222. As magnetism always exists, although in a latent state in iron, it is readily excited, or in other words the combined fluids decomposed, by various processes. A bar of soft iron placed in the magnetic meridian (215), almost instantly under the inductive influence of the earth, acting like a second magnet (211), acquires a low degree of polarity; if the iron be too close and compact to allow this ready decomposition, a few blows applied at one extremity, to cause it to vibrate, will generally aid the inductive influence of the earth, very considerably. A bar of iron heated red-hot, and allowed to cool in the direction of the magnetic dip (216), will generally be found magnetic, and bars of iron left for some time in this position, or one approaching to it, will acquire a low degree of magnetism: hence pokers, tongs, iron hooks, or other ferruginous bodies long left in a position of about 70 degrees with the horizon, are always found more or less magnetic. A thin piece of iron, as a piece of wire, may be rendered magnetic, by forcibly twisting it until it breaks. A strong electric discharge will produce a similar effect (376-8), and even, according to some observers, exposure to the violet rays of the prism.

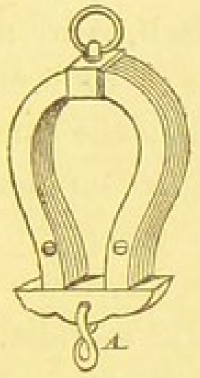
223. An iron bar may be rendered magnetic more readily by various processes, technically termed *touches*, all depending upon inductive action (213). The simplest mode, is to pass a pole of a magnet over the whole length of a bar of iron or steel, of course always in the same direction; the end of the bar last touched by the *boreal* pole of the magnet becoming an *austral* pole. This is usually termed the process of the *single touch*. Another and convenient mode, is to join the opposite poles of two magnets, AB, to place them over the centre of the bar of iron C, and to separate AB from each other, drawing them in contrary directions over C. They are then removed, again placed together, and reapplied to C, once more separated, and so on, the bar C ultimately acquiring a very energetic degree of magnetic intensity. The process of the *separate touch* is somewhat similar to the last, except that the ends of the bar C, *rest* upon the opposite poles of two sets of magnetic bars made by fastening four or five together, with their poles in the same direction. A and B are, instead of simple bars, similar compound magnets, not lying on the bar C, but elevated at an angle of about twenty-five or thirty degrees; they are united and separated, by drawing them to the opposite ends of the bar C, as in the last-described process. In the process of Œpinus, or the *double touch*, the bars are similarly placed, as in the *separate touch* last described, but the magnetising bars are inclined at an angle of fifteen or twenty degrees, and not separated; but moved from the middle to the ends of the bar of iron backwards and forwards, commencing and ending the friction in the middle. In the following figure, AB is the bar to be magnetised, *ns* and *n's'*,





the fixed magnets on which it rests, and NS, N'S' the moveable magnets, kept asunder at SN' by a small piece of wood: by this process very thick bars may be readily magnetised. The magnets employed in these processes do not give up any portion of their fluids to the bars, they are used merely to *excite* in the manner already explained (212); as each particle of magnetic fluid is firmly tied to the atom of iron to which it belongs, and consequently they do not suffer by the process.

224. Magnetic bars are sometimes bent into the shape of the letter U, and are then termed *horse-shoe* magnets, and several are not unfrequently fastened together, with their similar poles, in the same direction, constituting a *battery of magnets*. In this case they are peculiarly fitted for lifting heavy weights, as, by applying a bar of soft iron, A, to their poles, it becomes by inductive action (211), a magnet, and will adhere to the poles with a very considerable force. In constructing magnets, it is usual to draw, with a file, a line on that end of the bar which it is intended to convert into an *austral* pole, or that which, if freely suspended, would point towards the north pole of the earth.



225. Magnets, if left to themselves, gradually and in a space of time varying with the hardness of the metal composing them, lose their magnetic properties, from the recombination of the separated fluids. This is prevented by keeping their poles united, by means of a piece of soft iron, which, becoming magnetic by induction, reacts on the magnetism free in the poles of the magnetic bar, and tends to increase instead of diminishing their intensity. The power by which a bar of iron, or steel, retains its magnetic state is termed its *coercing force*.

226. The *coercing force* (225) of the other magnetic metals, especially nickel, is not so energetic as that of iron, according to the experiments of Biot. The bars used for these researches were prepared by Baron Thenard, and

were as free from iron as the chemical skill of that philosopher could render them: M. Biot found that the magnetic intensity of bars of steel and nickel, of the same size, were to each other as 0·002215 to 0·000684, the intensity of the steel magnet being more than three times as great as that of nickel. The magnetic intensity of cobalt has not been examined so carefully as that of nickel; indeed, it is doubtful whether the supposed magnetic properties of that metal, as well of chrome, titanium, and manganese, may not depend upon the presence of small traces of iron.

227. The magnetic intensity of the earth itself, is by no means constant, undergoing frequent variations in different parts of the world, as well as at different times in the same place. The comparative intensities of its magnetism may be observed by noticing the time required to complete a given number of oscillations of a magnetic needle, when a pole of the needle is thrust out of the magnetic meridian, as the intensity of the forces acting on a needle are to each other, as the squares of the number of oscillations performed in a given time.

On this subject I would refer the student to the late valuable report of Major Sabine, (Seventh Report, Brit. Assoc. 1838.)

228. A beautiful illustration of the mode of determining the intensity of forces acting on a needle, by the number of oscillations it performs in a given time, is found in the demonstration of the law of intensity of magnetic action, for which among a host of other invaluable investigations, science is indebted to M. Coulomb. A small needle suspended by a single thread, and protected from the influence of aerial currents, performed fifteen oscillations in one minute; let the directive force (220) of the earth producing these be called m. A long steel magnet placed in *the magnetic meridian*, had one pole approached to the distance of four inches from the needle, the latter made forty-one oscillations in one minute; the force thus exerted may be called m'. On

removing the pole to eight inches from the needle, the latter made twenty-four oscillations in the same time; this force may be represented by m''. The action of the magnet on the needle, in the first experiment, is $m'—m$, and in the second $m''—m$, because its effects resulted from its own force *plus* the attraction of the earth, thus,

$$\frac{m'-m}{m''-m}=\frac{(41)^2-(15)^2}{(24)^2-(15)^2}=\frac{1456}{351}=4{\cdot}148;$$

here, in the second experiment, when the distance of the needle from the pole was twice that of the first experiment, the magnetic intensity was found to be diminished, as nearly in accordance with the law, viz. of its being inversely as the squares of the distances, as experimental investigation could be expected to approach.

229. Artificial magnets have been constructed by reducing to powder the native magnetic oxide, and forming it into bars with wax and oil. They may also be constructed by forming the artificially prepared black oxide of iron, into bars with wax, and magnetising them by one of the processes already described (223).

A great number of mineral and even organic matters appear to exert a certain amount of action of low intensity, on the magnetic needle, so that, from the researches of Coulomb, it appears probable that almost every substance in nature is capable of assuming a faint and transient degree of polarity.

CHAPTER XI.

ELECTRICITY. (PRIMARY PHENOMENA.)

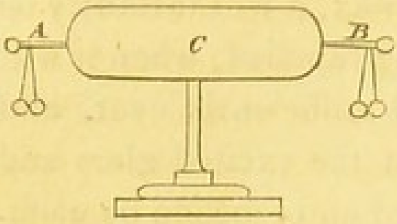
230. If a thick glass tube, previously made dry and warm, be briskly rubbed, for a few seconds, with a piece of silk or woollen cloth, also dry and warm, and then held near small pieces of paper or cork, placed on the table, these light substances will leap towards the *excited* tube, being attracted by it; and, after adhering to its surface for a short time, will be repelled towards the table, after touching which they will be again attracted by the tube; and these phenomena will be repeated, until the electricity excited on the surface of the glass vanishes. A piece of amber, sulphur, or sealing-wax, after excitation by a woollen cloth, will exhibit the phenomenon of attracting light bodies, like the glass tube.

231. Suspend a light ball of pith of elder, or cork, by a long silken thread from the ceiling, or any convenient support, and approach towards it an excited glass tube, the ball will be attracted, and, after adhering for a short time to the tube, will be repelled to a considerable distance, nor will it be again attracted until it has touched some substance connected with the earth, and thus given up the electricity it had acquired from the tube.

232. Whilst the pith ball is thus repelled by the tube, bring towards it an *excited* piece of sealing-wax, it will instantly be attracted by it, soon however becoming repelled, when it will rush towards the glass tube, if held sufficiently near, and thus vibrate like a pendulum between the excited glass and sealing-wax, being alternately attracted and repelled by each.

233. From these simple experiments we learn that the electricity excited by the friction of glass is communicated to pieces of paper, or pith balls, placed in contact with it, and that the bodies thus acquiring electricity are repelled by the tube, until after they have given up their acquired electricity to some body brought in contact with them; and as, when thus repelled by excited glass, the ball is attracted by excited resins, we have fair and valid reasons for concluding that the electricity developed in these substances by friction consists of two different species or kinds: that which is acquired by excited glass is termed the vitreous or positive electricity, and that by excited amber, wax, and resins, the resinous or negative electricity: we learn moreover *that bodies possessing one kind of electricity are attracted by those possessing the opposite kind, and repelled by those posesssing the same kind.* A substance possessing either species of electricity in a free state is said to be *electrified; negatively*, if its electricity be negative; and *positively*, if it be positive. In consequence of the wax, glass, &c., in the preceding experiments, acquiring electricity by friction, they are said to be *idio-electric*, whilst those not possessing this property, as metals, are termed *anelectrics.* From the general law of bodies, similarly electrified, repelling each other (233), we acquire a very convenient mode of detecting the presence of free electricity: instead of using a single pith ball (231), use two, fixed one to each end of a piece of thread; hang this, by the middle, across a fit support, and, on touching this little apparatus with the excited tube or sealing-wax, electricity will be communicated to it, and the balls, being similarly electrified, will repel each other, and separate to a considerable distance.

234. Insert into either end of a hollow cylinder of tin, supported by a glass leg, a rod of metal, as brass, B, and one of glass or sealing-wax, A, and suspend from each the pith balls, fixed to thread or cotton, now touch the cylinder C with an excited glass tube; immediately the pith balls suspended from the brass rod B will separate from each other, whilst those suspended from the glass A will remain unaffected. These curious phenomena arise from certain bodies, as metals, cotton, thread, &c. possessing the property of *conducting* electricity; whilst others, as wax, glass, silk, &c. are incapable of conducting this subtile form of matter. On this account, bodies have been divided into two great groups; *conductors* and *non-conductors* of electricity; the former being in general identical with *anelectrics*, and the latter with *idio-electrics* (233). The line of demarcation between these two great classes is by no means strictly definable, as a large number of substances exist which conduct electricity when present in large quantities, and insulate it when in small.



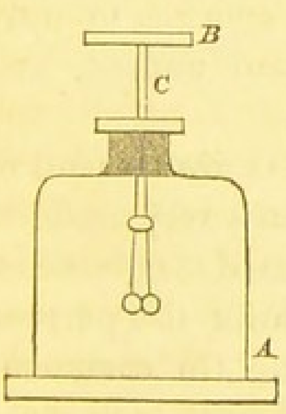
235. Among conducting bodies may be ranked, all metals, charcoal, water, steam, all animal and vegetable substances containing water, and many other substances; whilst glass, and all vitrifications, gems, resins, sulphur, metallic oxyds, organic substances perfectly free from water, and ice, are all more or less perfect non-conductors and idio-electrics. A substance placed upon a non-conductor, as when placed upon a stool with glass legs, is said to be *insulated*, from its electric connexions with the earth being separated.

236. Electric matter is universally present in nature, but in a latent state; the reason of which latter circumstance the preceding observations will enable us to understand. The two species, or negative and positive electricity, exist in nature *combined*, forming a neutral combination (in an analogous manner to the two magnetic fluids) (212), incapable of exerting any obvious physical actions on ponderable mat-

ter: by the process of friction, or other mechanical or chemical means, we decompose this neutral combination, the negative and positive elements separate, one adhering to the surface of the excited substance, the other to the rubber; hence, in no case of electrical excitation can we obtain one kind of electricity, without the other being simultaneously developed. We do not observe any free electricity on the surface of metallic bodies submitted to friction, in consequence of their so readily conducting electricity, that the reunion of the negative and positive fluids takes place as rapidly as they are separated by the friction employed.

237. Both forms of electric matter, separately, produce precisely the same physical effects on bodies, differing only in their properties in relation to each other. These electricities, although frequently called fluids, have but little claim to that designation; in using it, therefore, let it be always understood in a conventional sense, not as expressing any theoretical view of the physical states of electric matter.

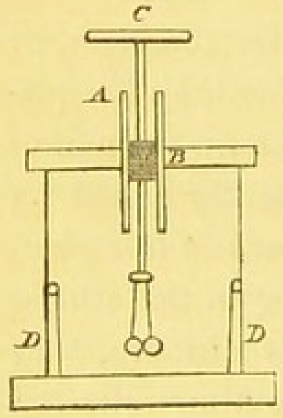
238. Certain pieces of apparatus, termed electrometers, or more properly electroscopes, are constantly called in requisition, in prosecuting the study of electric science; the pair of pith balls already described (233), are frequently called by this name, and employed to detect the presence of free electricity. As the currents of air always moving in the atmosphere, render the indications of the pith-balls obscure, they are frequently suspended by linen threads to a metallic rod fixed in the neck of a glass bottle or cylinder, A; on touching the top B of the apparatus with an excited piece of glass or resin, the electricity runs down the metallic rod C, in consequence of its being a good conductor, and reaching the pith balls, they, becoming similarly electrified, repel each other (232), and by their repulsion the presence of free electricity is indicated. The electric fluid does not escape from the rod C



to the earth, in consequence of the glass jar supporting it being a non-conductor, and therefore acting as an insulator (235).

The electricity thus acquired by the pith balls becomes slowly carried off by the circumambient air, which, from its always containing moisture, is a sufficiently good conductor for that purpose; for which reason it is absolutely necessary to carefully dry the exterior of the glass vessel, to ensure the success of an experiment. To prevent the deposition of moisture on this as well as all other pieces of electric apparatus, it is a very good plan to cover the upper part of the glass externally with a solution of shell lac in alcohol, this, on drying, leaves a nearly transparent covering of an excellent insulating substance, which is less liable to attract moisture from the air than the naked glass.

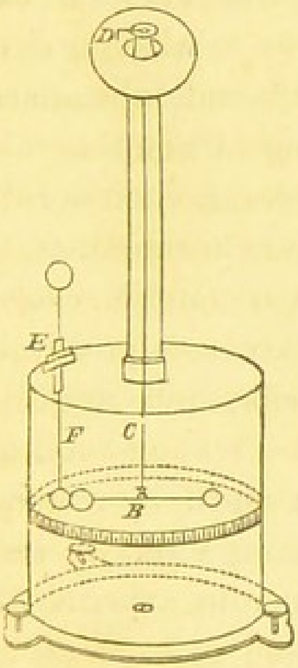
239. The best electrometers are generally furnished with a contrivance invented by the late Mr. Singer; in this the metallic rod to which the pith balls are attached, passes through a glass tube, covered externally with lac varnish; this rod is retained in its place at B by a plug of silk, lac, or other non-conducting substance; the advantages of this arrangement are sufficiently obvious, for it is evident that any electricity communicated to the rod C, cannot escape to the earth, until the whole of the interior of the tube A, become covered with moisture. I have repeatedly found such an instrument perfectly sensible to mere traces of electricity, after having remained unused, and even covered with dust, during six months.



As it is often necessary to discharge these instruments of all the electricity communicated to them, it is very useful to paste two slips of tin-foil DD along the inside of the glass case of the instrument, touching its base, which for this purpose must be of metal or some good conductor. On communicating electricity to such an electrometer, the pith balls separate, and, striking the slips of tin-foil, give up to them their free electricity, which escapes by the wooden or metallic base of the instrument to the earth.

240. When we have occasion to detect very minute quantities of electric matter, the weight of the pith balls in the last-described electrometer interferes too much with the delicacy of the instrument; on this account two slender slips of leaf-gold, hanging parallel to each other, are with great advantage substituted for the pith balls. A gold-leaf electrometer, with Singer's mode of insulation (239), furnishes us with the most delicate instrument for the detection of small quantities of electricity which has yet been contrived.

241. All the instruments above described, merely indicate the *presence*, and not the *quantity* of electricity present in any substance in a free state; for a mode of gaining an approximation to the knowledge of proportions of electricity, we are indebted to the sagacity of M. Coulomb, whose



torsion balance well fulfils the expectation of its contriver. It consists of a slender beam, B, formed of a filament of lac, furnished with a gilded pith ball at one end, and a little vane of paper at the other; this is suspended by a fine metallic wire, C, or still better, by a filament of spun glass, in the middle of a cylindrical, or square cage of glass. The upper end of this wire, or glass thread, terminates in a key, D, furnished with an index, the whole capable of moving in the centre of a circle, G, graduated into 360°; through a hole, E, at the top of the glass cage, a rod of lac, F, terminating in a gilded ball, is inserted; being prevented falling in by a stop at E. To use this instrument to detect the presence of free electricity, the rod F is removed, and its ball brought in contact with the substance whose electricity is to be examined; the ball acquires some of the free electric fluid, and on being placed in the glass cage, it communicates some of its electricity to the ball, terminating the horizontal needle, B; the two being similarly electrified repel each other; and as F is fixed, B necessarily moves, and describes a certain angle, which it retains until it loses its electricity: to measure the quantity of fluid thus acquired, the key D, to which the glass thread C is fastened, is turned round, until, by the torsion, or twisting of the thread, the ball of B is compelled to come in contact with that of F. The number of degrees described by the index fixed to the revolving key, D, gives us an approximation to the proportion of electricity acquired by the ball of F, during its contact with an electrified body.

242. It has been already stated, that in no instance can one kind of electricity be excited without a corresponding portion of the other being set free; in the present state of our knowledge, no general rule can be given as to what form of electricity is acquired by the friction of different substances, further than what date the results of experiments on this subject have furnished us with. Many substances, excited or rubbed by one rubber, evolve negative, and when submitted to the friction of another composed of a different material, evolve positive electricity; thus, smooth glass becomes positively electrified, when rubbed by flannel or silk, and negative when excited by the back of a living cat. Sealing-wax, on the other hand, becomes positive when rubbed by metallic substances, and negative by almost everything else. A very useful table, exhibiting the results of numerous experiments has been given by Cavallo:

Substances excited.	Kind of Electricity.	Material forming the Rubber.
Back of a cat ...	Positive ...	Every substance hitherto tried.
Smooth glass ..	Positive ...	Do., except the back of a cat.
Rough glass ...	Positive ...	Dry oiled silk, sulphur, metals.
...	Negative	Woollen-cloth, paper, wax, human hand.
Tourmaline ..	Positive ...	Amber; a current of air.
...	Negative	Diamond, the human hand.
Hare's skin ...	Positive ...	Metals, silk, leather, hand.
...	Negative	Other finer furs.
White silk ...	Positive ...	Black silk, metals, &c.
...	Negative	Paper, hand, hair, &c.
Black silk ...	Positive ...	Sealing wax.
...	Negative	Furs, metals, hand.
Sealing-wax ...	Positive ...	Metals.
...	Negative	Furs, hand, leather, cloth, paper.
Baked wood ...	Positive ...	Silk.
...	Negative	Flannel.

243. Electricity is not only set free by friction, but by almost every form of mechanical change to which any substance can be submitted; mere pressure is quite sufficient for this purpose. Take two pieces of common window-glass, each presenting a surface of about four square inches, to the centre of each fix a piece of sealing-wax, to serve as a handle; press the discs firmly together, and, whilst in this state, approach them to a gold-leaf electrometer (239), no divergence of the slips of gold will ensue; but suddenly separate the pieces of glass, and bring one of them near the electrometer, and the instant separation of the gold leaves will demonstrate the presence of free electricity in the discs, one of which will be found positively, and the other negatively electrified. Sulphur poured, whilst melted, into a conical glass, and furnished with an insulating handle, as a piece of glass or silk, will, when cold, indicate no free electricity, until the cone of sulphur be lifted from the glass, and then the former will be found negatively, and the latter positively electric.

244. Certain minerals, especially tourmaline, and many of the family of zeolites, have their neutral and latent electricity decomposed and developed by heat, one extremity of the

crystal becoming negative, and the other positive. When a prism of tourmaline is gently heated at one extremity, its electricity becomes decomposed, the negative passing to one, and the positive to the other end of the crystal; signs of free electricity gradually increasing as we advance from the middle, where they are absent, towards either extremity of the prism. The distribution of electricity being strikingly analogous to that of magnetism in a magnet, according to the hypothetical formula of Eschenmaier (213), which, setting e with the positive co-efficients for *positive*, and with the negative for *negative*, electricity, will stand as applied to the heated tourmaline, thus

$$e^{n} \ldots\ldots\ldots e^{3}\ e^{2}\ e^{1}\ e^{0}\ e^{-1}\ e^{-2}\ e^{-3} \ldots\ldots\ldots e^{-n}.$$

It may be stated that, in general, no idio-electric substance (233) can be pressed, bruised, rubbed, or submitted to a change of temperature, without suffering some decomposition of its neutral and latent electricity; one or the other kind being developed in a free state in the ~~crystal~~ body, in greater or less proportions, according to circumstances.

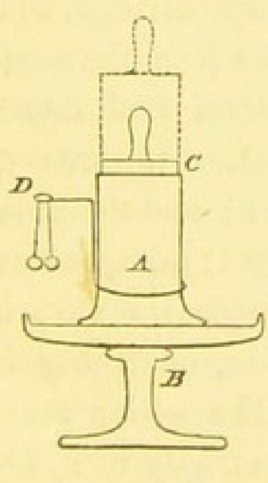
245. If the excitation of the glass tube (230) be performed in a darkened room, a pale lambent flame will be observed on its surface, each time the tube is drawn through the piece of silk, accompanied by an odour like that of phosphorus; and on bringing the glass near any conducting body, as the hand, a small but vivid spark will be observed to fly towards it, attended with a faint but sharp crackling noise. The evolution of this electric light was first distinctly noticed by Otto de Guericke, at the latter end of the 17th century, whilst submitting a globe of sulphur to the friction of the hand; about the same time, Boyle* observed the light emitted by an *excited* diamond; and Dr. Wall that given off from a piece of *excited* amber, on the approach of the finger.

* Boyle's Works, vol. iii. p. 152.

246. The readiest mode of observing this electric light, consists in drawing a piece of dry and warm brown paper, about eighteen inches long and four broad, through a piece of warm flannel, on bringing the hand near the paper, as it is rapidly withdrawn from the folds of the flannel; bluish flashes of light, two and three inches in length, will be darted off in various directions, accompanied by a loud crackling noise.

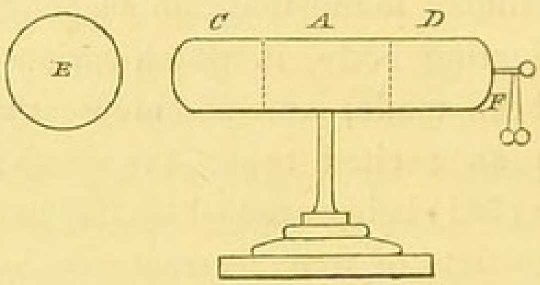
246*. Electricity thus excited in, or communicated to any substance, does not appear to penetrate into the interior of the mass to any extent, but to reside almost exclusively upon its surface. Coulomb found that, on suspending, by silken threads, a conducting body, in which various pits and depressions had been made, and communicating to it some electricity from an excited tube, the carrier ball of his electric balance (241) being applied to the bottoms of these cavities, gave no sign of free electricity on being placed in the electrometer; although, when brought in contact with the surface of the conductor, it became strongly electrified; thus proving that electricity is almost entirely limited to the surfaces of insulated bodies.

247. As a necessary consequence of this law, we find that the quantity of electricity remaining the same, its effects on the electrometer become diminished, by increasing the surface to which it is confined.



Exp. A hollow tin cylinder, A, about eight inches in length, is insulated by a glass support, B: an inner cylinder, C, provided with a glass handle, moves readily in the outer one; from the latter passes a curved wire, D, to which a cork-ball electrometer is suspended. Now, touch A, with an excited glass tube, the electricity diffusing itself over the apparatus, will cause the pith balls to become electrified, and consequently repel each other; when these balls are about one third of an inch apart, raise the inner cylinder c, by its glass handle, as high as possible, without entirely removing it from A; the electricity will now be expanded over twice its previous superficial extent, and a smaller quantity will be left in the pith balls, which will consequently approach each other: then depress the inner cylinder c, the electricity will again be spread over a lesser surface, and the pith balls will separate as at first.

248. Let DAC be a conducting body, as a cylinder of turned iron, placed on an insulating support; a cork ball



electrometer F, being suspended from one end of the cylinder. Now *approach* any positively electrified body, E, as an excited tube, about six inches from C, the pith balls F will instantly separate, indicating the presence of free electricity; this could not arise from any electric fluid having passed from E to C, as on removing E, to a considerable distance, the balls F will fall together, and appear unelectrified; on again approaching E to C, the balls will again diverge, and so on. This very curious phenomenon, arises from the positive electricity in E, decomposing the neutral and latent combination (9) in DAC, attracting the negative towards C, and repelling the positive electricity towards F; and the balls consequently diverge, being positively electrified; on removing E, the force which separated the two electricities in DAC, is removed, and the separated elements reunite, neutrality is restored, and the pith balls fall together. The action exercised by E, is called *induction*, from the electricity in E, *inducing* a change in the electric state of DC.

249. If the cylinder DC, be carefully examined whilst within the inductive influence of the positively electrified ball, E, it will be found to have the end C, negatively electric, and at the end D, positively; whilst an intermediate zone, A, will be found neutral and unelectrified, so that the distribution of electricity on its surface may be compared to that in an excited tourmaline (244): whilst things are in this state, and the pith balls standing apart from each other, touch the cylinder DC, with the finger, or any other conducting body connected with the earth, the pith balls will collapse, from the positive electricity running off by the finger to the earth; the negative electricity cannot escape in the same manner, because it is firmly held in the end C, of the cylinder, by the attractive influence of the opposite electricity of the ball, E. Now remove the finger, leaving the conductor insulated, and separate E, to a considerable distance from C, the negative electricity in which, being released from the influence of E, expands itself over DC, and the positive electricity which had been previously combined with it, having been removed by touching it with the hand, it is left in a free state on DC, and the balls F instantly separate with *negative* electricity. If this experiment be repeated with an *excited* piece of sealing-wax, amber, or sulphur, instead of the glass tube, E, the same phenomena will occur, with this difference, that the induced electricity will always be of the opposite kind, as would of course, be expected *à priori*.

250. The application of this inductive influence, furnishes us with the readiest mode of ascertaining the kind of electricity present in any excited substance; for this purpose, excite a glass tube by friction, and hold it about a foot distant from the cap of the gold-leaf electrometer (239); the leaves will diverge with positive electricity, the negative being retained in the cap of the instrument: touch the latter with the finger, the leaves collapse, and the *positive* electricity escapes to the earth; the *negative* being retained in

the cap by the attraction of the positively electrified tube. Now, remove first the finger, then the tube, and the gold leaves will diverge with *negative* electricity ; excite, by friction or otherwise, the substances whose electric state is to be examined, and hold it near, but not in contact with, the cap of the electrometer ; if the substance be positively electrified, it will attract the negative electricity from the gold leaves into the cap of the instrument, causing the former to collapse ; whilst, if it be negative, it will, by repelling the electricity of the same kind already in the electrometer, increase the previously divergent state of the gold leaves. By this process, it becomes exceedingly easy to discover what species of free electricity is present in any excited substance.

251. In these experiments (248-250), the induction takes place through the column of air separating the excited tube from the conductor (248), or electrometer (250). A similar action is capable of taking place when other non-conductors are interposed ; these substances, in consequence of their permitting induction to take place through them, have been termed *dielectrics*. These dielectrics differ considerably in the degree of facility with which they permit induction to take place through them, indicating the existence of a specific inductive capacity. Thus, sulphur, lac, and glass, have much higher inductive capacities than air.*

252. Induction has been demonstrated by Faraday, to be essentially a physical action, *occurring between contiguous particles, never taking place at a distance, without polarizing the molecules of the intervening dielectric ;* thus, in the experiment already detailed (248), a space of six inches occurred between the *inducting* excited tube and the conductor, whose electricity was affected by its action : we are not to assume from this, that the decomposition of the neutral electric state of the conductor arose from an action at a

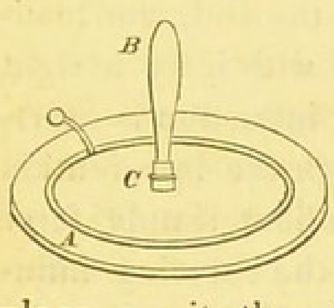
* On this subject, the admirable papers of Dr. Faraday, in the Philosophical Transactions for 1838 should be consulted, especially § 1252-78.

distance; for most satisfactory evidence has been adduced by Dr. Faraday that the intervening dielectric, air, has its particles of electricity arranged in a manner analogous to those of the conductor DC, by the inducting influence of the glass tube. The theory of induction depending upon an action between contiguous molecules is supported by the fact, which would be otherwise totally inexplicable, that a slender rod of glass or resin, when excited by friction and placed in contact with an insulated sphere of metal, is capable of decomposing the electricity of the latter by induction, most completely, even at the point of the ball equidistant from the rod, and consequently, incapable of being connected with it by a right line; so that we must either consider that induction is exerted in curved lines, or propagated through the intervention of contiguous particles. Now, as no radiant simple force can act in curved lines, excepting under the coercing influence of a second force, we are almost compelled to adopt the view of induction acting through the medium of contiguous particles.

253. This inductive action appears to come into play in every electric phenomenon; thus, in the simple experiment of attracting light bodies by an excited tube (230), the positive electricity in the tube decomposes by induction the electricity of the pieces of paper, repelling their positive fluid; and being thus left in a negative state, they become attracted by the tube, in obedience to the law of mutual attraction between differently electrified bodies. The following experiment illustrates in an interesting manner the development of electricity by induction. Support a pane of dry and warm window-glass about an inch from the table, by means of two books or blocks of wood; and place beneath it several pieces of paper or pith-balls. Excite the upper surface by friction with a silk handkerchief, the electricity of the glass becomes decomposed, its negative fluid adhering to the silk, and its positive to the upper surface of the glass-

plate ; this by induction acts on the lower surface of the glass, repelling its positive electricity and attracting its negative. The lower surface of the glass, thus becoming virtually electrified by induction through its substance, attracts and repels alternately the light bodies placed beneath it, in a similar manner as the excited tube (230).

254. Into a circular tray of tinned iron, A, about eight or ten inches in diameter and ~~twelve~~ one inches deep, pour melted sealing-wax, or a mixture of two parts of shell lac and one of Venice turpentine, until it is filled, and let it cool gradually. A circular plate of stout tinned iron, or brass, about two inches less in diameter than A, is furnished with a glass handle, B, fixed into its centre. Remove the metallic plate from the cake of resin or sealing-wax A, and excite the latter by friction, with a warm and dry piece of flannel ; then place on it the plate C: under these circumstances the negatively electrified cake of resin decomposes the natural electric state of C, attracting its positive fluid into the lower surface, and repelling its negative into the upper, by induction. If then C be lifted off by its glass handle, its separated electric fluids will reunite, and it will be found destitute of free electricity ; replace C on A, touch the former with the finger, and its ~~positive~~ negative electricity, repelled by the inductive influence of A, will escape to the earth ; then raise C, by its handle B, it will be found to contain positive electricity in a free state, which, on the approach of any conductor, will escape in the form of a vivid spark, the plate resuming its naturally unelectrified state. Again, place C on A, touch it with the finger, negative electricity escapes to the earth ; lift off C, approach any conductor towards it, and another spark of positive electricity occurs. This process may be repeated an almost indefinite number of times, the cake A losing none of its electricity by the operation, as it acts solely by its inductive influence on the combined electricities actually



present in the metallic plate D; indeed, after being once excited, a spark may be obtained from this instrument, during many weeks, without any fresh excitation, and on this account it has been used as an electrifying machine, and was by its inventor, the celebrated Volta, termed *electroforo perpetuo*. This electrophorus is a most valuable instrument, not only from its affording a beautiful illustration of inductive action but from its yielding a large supply of electricity.

255. A very useful modification of the electrophorus (254), is made by coating a thin pane of glass on one side with tin-foil to within about two inches of the edge. Placing it with the coated side on the table, excite the other surface by friction with a piece of silk covered with amalgam (264), then carefully lifting the glass by one corner, place it on a badly-conducting surface, as a smooth table or the cover of a book, with the *uncoated side downwards*. Touch the tin-foil with the finger, then carefully elevate the plate by one corner, and a vivid spark will dart from the coating to any conducting body near it; replace the plate, touch it, again elevate it, and a second spark will be produced. An electric jar may be charged, in a few minutes, with an apparatus of this kind only four inches square. This modification of the electrophorus, or electro-lasmus,* as I termed it when I first constructed it several years ago, is a most convenient instrument in the laboratory where electricity is required for endiometric purposes, and where the introduction of an electric machine (260) is inconvenient.

256. If a given quantity of free electricity be communicated to a surface exposing sixteen square inches, and a similar quantity be communicated to another of but four square inches of surface, it is obvious that every square inch of the former will contain but one fourth of that present in every square inch of the latter; hence, although the total quantities

* ἤλεκτρον and ἔλασμος, lamina.

of free electricity are similar in each, yet as, in the former, they are spread over four times the surface that they are in the latter, they will be found as much less energetic in producing the phenomena of attraction, and repulsion, induction or light. The electricity present in the smaller surface, is consequently said to be in a state of greater *tension* than in the larger.

257. A rounded surface, as a brass knob, on being held near to, or communicated with an electrified body, allows induction to take place with much less facility than a pointed wire similarly situated, on account of the inductive action being confined to, or excited from a smaller surface, causing thereby a greater electric tension (256) on the surface of the point, than of the knob; for this reason, whilst a rounded surface may be approached within an inch of an excited tube (230), without abstracting much of its free electricity, the point of a sharp needle, held at four times that distance, will almost immediately effect the neutralization of the free electricity present in the tube. For this reason, all pieces of apparatus destined to retain free electricity, are terminated by knobs or rounded surfaces; and those intended rapidly to abstract, or neutralize this electric matter are furnished with points. On this circumstance is explained the fact of an electrified sphere having its electricity equally diffused over its surface, whilst, in the case of an ellipse, the greatest quantity is found at the termination of its long diameter, and of a cube at the apices of its angles.

258. Having considered some of the principal and simplest phenomena of electricity in a general sense, it becomes necessary to be acquainted with the nature of the exact laws governing them; for a knowledge of these, we are almost entirely indebted to the researches of M. Coulomb, who brought to bear, on this subject, the most accurate experiments with the most refined and valuable instruments of mathematical investigation.

Primary Electrostatic Laws.

(A.) Two bodies, similarly electrified, repel each other (233) with a force, varying inversely as the squares of their distances.

(B.) Two bodies, differently electrified, attract each other, (232) with a force, inversely as the squares of their distances.

(C.) Electricity, in its natural and compound state, appears to be diffused equally throughout any given mass of matter; but when decomposed and separated into its component elements, each of the fluids is confined to the surface of the substance in which it has been set free, in the form of an exceedingly thin layer, not penetrating sensibly into the substance of the mass.

(D.) Bodies, carefully insulated on resinous supports, lose, by exposure to the air, a certain proportion of their free electricity, depending to a great extent upon the moisture present in the atmosphere; the loss, per minute, appearing to bear a ratio to the cube of the weight of hygrometric moisture in the air.

(E.) Bodies electrified and insulated imperfectly, as on silk, or glass uncovered with resin, lose a portion of their electricity, by its escaping along the imperfectly insulating support, providing the electricity is of considerable tension, for if weak, it is completely insulated; hence the loss of electricity is, at first rapid, but quickly decreases.

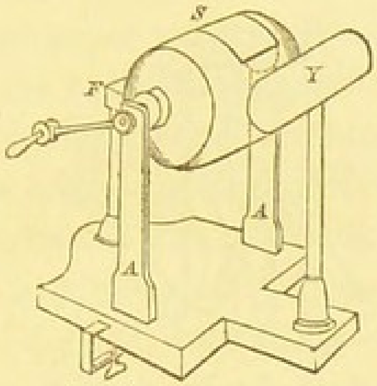
CHAPTER XII.

ELECTRICITY. CONSEQUENCES OF INDUCTION.

259. WITH the exception of the electrophorus, we have as yet not had recourse to any instrument furnishing large quantities of free electricity. The first machine constructed for this purpose was contrived by Otto de Guericke, of Magdeburg: it consisted of a globe of sulphur, turned by a winch, and submitted to the friction of the hand. Very gradually were improvements introduced into its construction; first a globe or cylinder, of glass, was substituted for the sulphur, and then a silk rubber was used, in lieu of the hand; the last great addition consisting in the adaptation of a metallic conductor, to collect the electricity excited. The revolving glass electric was used by Hawksbee in 1709, the rubber and conductor being introduced in 1741; Boze, of Wirtemberg, contriving the latter, and Winkler the former; thus rendering the electric machine nearly complete.

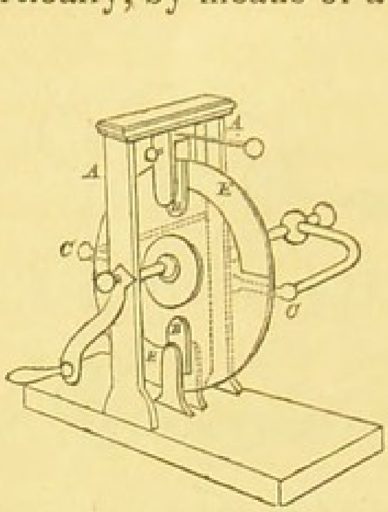
260. Two forms of the electrical machine are used in this country, differing chiefly from each other in the shape of the revolving electric, which in one is a cylinder, and in the other

a plate ; each varying in diameter from eight or ten inches to two feet, beyond which size it is inconvenient to use either.



The best form of cylindric electrical machine, consists of a cylinder of glass, revolving by means of a winch, between two upright pieces of stout and well-dried wood, AA ; this is submitted to the friction of a rubber, formed of an oblong piece of wood, F, about three or four inches shorter than the cylinder, covered with leather, and furnished with a flap of silk, S, extending over nearly half the circumference of the glass. The rubber is supported by a strong glass pillar, and connected with a sliding piece of wood, which, by means of a screw permits the rubber to be placed at any distance from the cylinder. On the opposite side to the rubber, is a cylinder Y, of hollow tinned iron, or, what I greatly prefer, of wood covered with tin-foil, nearly as long as the glass cylinder, to which it is parallel, and about three or four inches in diameter ; this like the rubber is supported on a glass leg, the side next to the glass cylinder is furnished with a row of pointed pieces of wire, to allow of its more rapidly acquiring an electric state (257), from the revolving glass. This piece of apparatus is termed the prime conductor, and has a number of holes, of various diameters, bored in it, to permit the insertion of wires of various sizes ; the edges of these holes, as well as every other part of the conductor, except the points already mentioned, must be carefully freed from all sharp edges or prominences, which cause a rapid neutralization of electricity.

261. The plate machine consists of a circular plate of thick glass, revolving vertically, by means of a winch, between two



uprights AA; two pair of rubbers, formed of slips of elastic wood covered with leather, and furnished with silk flaps, are placed at two equidistant portions, BB, of the plate: their pressure upon the latter may be increased or diminished by means of brass screws. The prime conductor consists of hollow brass, supported horizontally from one of the uprights A; its arms, where they approach the plate at CC, are furnished with points, for the same reason as in the cylindric machine.

It is very difficult to give an opinion of the comparative merits of these two machines,—for an equal surface of glass, however, the plate appears to be the most powerful; it has, however, one great inconvenience, viz., the difficulty of obtaining negative electricity from it, in consequence of the uninsulated state of its rubbers.

262. When an electrical machine is required for use, it should be placed within the influence of a good fire, so that its several parts may become dry and warm: the rubber and conductor are then to be removed, and the plate or cylinder rubbed with a piece of flannel, dipped in oil, until it becomes quite clean and bright; the layer of oil thus left, being removed with a linen cloth. The rubbers are then to be made quite dry, and their silk flaps wiped clean; a little amalgam made into a soft paste with lard, to be spread over

the surface of the cushions of the rubbers, unless there happens to be plenty left on from a previous experiment, in which case the surface is to be cleaned by rubbing it with a piece of rough brown paper, or by scraping it with a knife. The rubber, or rubbers are to be then applied, and by means of the adjusting screws, made to press moderately against the surface of the cylinder or plate ; on then turning the winch, and holding the hand towards the revolving glass near the lower surface of the silk flap, the electricity will be felt rushing between the hand and glass, like a brisk wind, attended by a crackling sound, and in the dark, by a lambent blue flame. The prime conductor is next placed, in such a manner that its points stand about one eighth of an inch from the glass : on holding the hand towards it, and turning the winch, vivid sparks, often some inches in length, appear ; these are attended by a loud snapping noise, and on striking the hand, produce a pungent pricking sensation, often producing a papular eruption on the skin.

263. The development of free electricity upon the prime conductor is so intimately connected with the theory of induction already developed (248), that the remarks there made, will be sufficient to remove all obscurity as to the mode in which it is effected. On turning the glass plate or cylinders, the electricity naturally present in the rubber becomes decomposed, its positive adhering to the surface of the glass, and its negative to the rubber ; the positive electric portions of the glass coming, during its revolution, opposite to the points on the conductor, act powerfully by induction upon the latter, decomposing its electricity into the component fluids, attracting the negative, which being accumulated in a state of tension (256), at the points of the conductor, dart off towards the cylinder, to meet the positive fluid, and thus reconstitute the neutral compound; the prime conductor is thus left powerfully positive, *not by acquiring electricity from the revolving glass, but by having given up its own negative fluid to*

the latter. The rubber is left in a proportionately negative state, and consequently, after revolving the glass for a few minutes, can develop no more free positive electricity, providing the rubber be (as in the cylindric machine) insulated; on this account, it is necessary to make it communicate with the earth, for the purpose of obtaining a sufficient supply of positive electricity to neutralize its negative state. In very dry weather, indeed, the electric machine will frequently not act, until the rubber is connected by a good conductor, not merely to the tube supporting it, but to the moist earth, or, what in large towns is more convenient and preferable, with the leaden pipes supplying the building with water.

264. Much discrepancy of opinion has existed concerning the modus agendi of the amalgam applied to the rubber; it certainly acts very powerfully in increasing the excitation of electricity; the best for this purpose consists of two parts of zinc and one of tin, melted together, and added to six parts of mercury, previously heated in a crucible: the mixture being stirred until cold, is readily reduced to a fine powder, which requires merely to be formed into a paste with lard to be ready for use. It has been, with good reason, supposed that the oxydation of the amalgam, by the friction employed, is essential to the increased excitation; for amalgams of gold, and other difficultly oxydizable metals, do not increase the development of electricity; and, in accordance with this view, Dr. Wollaston found that an electric machine, when worked in an atmosphere of carbonic acid, gave no signs of free electricity. Instead of an amalgam, the deutosulphuret of tin, or aurum musivum, may be rubbed upon the cushions of the machine, and with similar results. This latter substance acts probably like the amalgam, by undergoing oxydation, as by friction it gives rise to the formation of bisulphate of tin; in a similar manner also iron pyrites, by friction, is partly converted into sulphate of iron. The chemical influence of friction, indeed, is more energetic than is usually supposed; even siliceous minerals), as mesotype, basalt, and feldspar, become

partly decomposed, giving up a portion of their alkali in a free state.

265. When the plate or cylinder of the machine is turned, the rubber communicating to the earth by a metallic chain, if a brass knob, or a knuckle be held towards the prime conductor, a vivid spark darts between them: this spark is usually spoken of as a positive spark, as though it consisted of positive electricity passing from the conductor towards the knob, or knuckle. This, however, is an erroneous expression; for, as the prime conductor is positively electrified, it induces (248) an oppositely electric state in any conducting substance approaching it; and when this state has amounted to one of sufficient tension, the negative electricity rushes towards the positive of the prime conductor, and constitutes the neutral combination. This neutralization, or *discharge* of the electric state of the conductor is attended by a sharp snapping sound, and a flash of light, constituting the electric spark; consequently, whenever an electric spark is seen, it is not to be regarded as arising from the mere passage of free electricity, but of the union of the two electric fluids, and consequent discharge of the electrified body. The sparks of *positive* electricity said to pass from the excited tube (245), or cover of the electrophorus (254), are of the same kind. From these facts also, we deduce the necessary consequence that all cases of discharge must be preceded by induction.

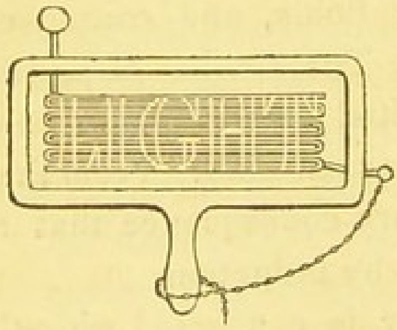
266. When the prime conductor is connected with the earth, and the *rubber* of the machine insulated, sparks are seen on approaching the hand, or other conductor, towards it; these are termed sparks of *negative* electricity, but as erroneously as in the case of sparks from the prime conductor; as they arise from the discharge of the free electricity in the rubber, by its union with the induced positive electricity in the nearest conducting body.

267. If both conductor and rubber of the machine be insulated, and a pointed wire held at a short distance from each, the positive electricity will be seen leaving the wire

held towards the rubber, in the form of a luminous *pencil* or *brush;* whilst the point of that held towards the conductor will be illuminated by a small *star* of light. These different appearances probably arise from the different degrees of facility with which the two fluids traverse a badly conducting medium, the positive appearing to effect its traverse through the air, with much greater readiness than the negative.

268. If the conductor, or rubber of the electric machine, be connected with each other, or the earth, by means of a continuous conductor, as a piece of wire, the electric fluids will traverse, and discharge take place along it invisibly, unless the machine be extremely energetic, in which case the wire will appear surrounded by a lambent flame. But if the conductor be interrupted, then vivid sparks will appear at each rupture of continuity, arising from inductive action and consequent discharge taking place at every one of these spots.

Exp. (A.) Connect the prime conductor and rubber with each other, by means of a brass chain; on working the machine, vivid sparks will appear at every link.



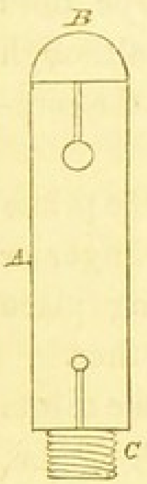
Exp. (B.) On a plate of glass, paste some strips of tinfoil, having portions cut out, so that the spaces represent letters; then on communicating the first piece of foil with the conductor, and the last with the ground, the letters will appear in characters of fire, from a spark occurring at each division of the foil.

Exp. (C.) Draw, on a pane of glass, a serpentine line with varnish, and place on it, before it dries, metallic spangles, about one tenth of an inch apart; on connecting this with the machine, a serpentine line of fire will be represented.

Exp. (D.) If, in a similar manner the spangles are placed on a glass tube in a spiral direction, a fine spiral line of spark will be produced.

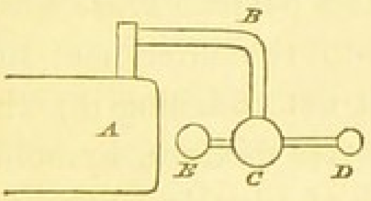
269. Induction, and consequent discharge, take place

through a greater space in an air-pump vacuum, than under ordinary atmospheric pressures, a circumstance arising from the resisting dielectric medium being removed; this led to the error of considering a vacuum as a conductor of electricity, which is not the case, discharge being effected through it readily, only if the two surfaces be sufficiently near to permit induction to take place, otherwise, electrified bodies can be as well insulated in an air-pump vacuum as in common air.



Exp. (A.) A glass tube, two feet in length A, is furnished at either end with a brass ball projecting into its interior, and carefully exhausted of its air, by means of a good air-pump: on connecting its upper end B, with the prime conductor, and its lower end C with the earth, if the machine be turned, B becomes positive, and induces a contrary state on the ball at C, induction taking place with facility in consequence of the atmospheric pressure being removed, and is followed by a discharge of the two electricities in the form of a beautiful blue light, filling the whole tube, and closely resembling the aurora borealis.

270. In all these experiments (268-9), it is better to allow the electricity, before passing through the tinfoil, chain, or luminous conductor (269), to acquire some degree of tension; this is conveniently effected by means of an instrument called Lane's *electrometer*, or more properly, *discharger*. This consists of a curved arm of varnished glass, B, fixed by a brass leg into the prime conductor A, and terminating in a ball, C, through which passes a rod furnished with two brass knobs, capable of being placed at any distance from the conductor. If any of the above-described pieces of apparatus be connected with the ball D, electricity will be set in motion through them, as soon as it has acquired a sufficient state of tension to effect a discharge between A and E.

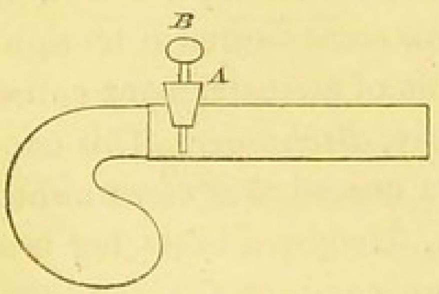


271. Every conducting substance, insulated and connected with the prime conductor, or rubber, may be considered as part of them, as far as their electric state is concerned: thus, if a man standing on a stool furnished with insulating glass legs touch the prime conductor, he virtually becomes part of it, being similarly electrified, and all the phenomena proper to the prime conductor may be observed at any part of his surface.

272. The electric spark, or more properly *discharge*, does not impart to the finger a sensation of sensible heat, although it is capable of exciting sufficient caloric to produce the combustion of inflammable substances.

Exp. (A.) Connect a shallow metallic cup with the prime conductor, and pour ether into it; on holding the finger or a knob of brass over it, the electric discharge taking place through it will evolve sufficient heat to inflame the ether.

Exp. (B.) Put into a bottle granulated zinc, and some dilute sulphuric acid; fix in its neck a cork furnished with a tube, terminating in a small aperture; hydrogen gas will issue from it, and, on holding it close to the conductor, and by means of a brass knob drawing a spark through the stream of gas, it will burst into flame.

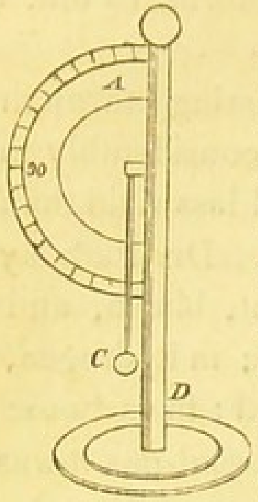


Exp. (C.) A brass tube, mounted on a stock like a pistol barrel, is furnished with a glass or ivory tube, screwed into A. Through this passes a brass wire, passing into the interior of the barrel, but not touching it; the brass tube is then filled with an explosive mixture, by holding it for a few seconds over the mouth of a bottle containing the ingredients for the production of hydrogen gas. On closing the mouth quickly with a cork, the charge is retained, and on approaching the knob B to the prime conductor, a spark is produced in the interior of the barrel, the gases are exploded, and the cork driven out with considerable violence, attended with a loud report; this apparatus is termed Volta's electric pistol, from the name of its inventor.

273. The electric spark (discharge), passing through media differing from atmospheric air, varies considerably in tint. Thus, in rarified air, its light is blue and less vivid than when under ordinary atmospheric pressures. Dr. Faraday found that, in nitrogen, it was very brilliant, bluish, and sonorous; in oxygen, less brilliant and white; in hydrogen, crimson, and accompanied by little or no sound; in carbonic acid its tint was rather greener than in air; in coal-gas it was green or red, sometimes both, with frequent interruptions by black spots; and in hydrochloric acid gas, white without any of the dark spots so frequently present in the cases of the other gases. Occasionally, the spark appears interrupted in its centre by a non-luminous spot, owing to discharge taking place at that point in a more diffused manner than nearer the inducing surfaces.

274. In common air, the luminous electric discharge, or spark, becomes modified in tint according to the surface at which it takes place; thus, from a large brass ball, it is white and brilliantly luminous, whilst, as we diminish the size of the ball, it becomes bluer and more scattered, assuming the form of a brush, which itself depends upon a series of intermitting discharges taking place with considerable rapidity. From the surface of ivory, the discharge is crimson coloured; from silvered leather it is green; from powdered charcoal, yellow; and purplish, when taking place on the surface of most imperfect conductors of electricity. The light of the electric discharge is capable of undergoing decomposition by a glass prism, and polarization by reflection or absorption, like ordinary light.

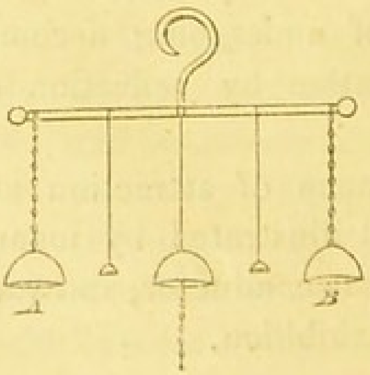
275. The phenomena of attraction and repulsion (231) are exceedingly well illustrated by means of the electricity belonging to the prime conductor, and various toys have been contrived for their exhibition.



Exp. (A.) Fix into one of the holes of the prime conductor the instrument, called Henley's electrometer, consising of a graduated semicircle of ivory, fixed to a rod of wood D. From the centre of A depends a light index, terminating in a pith ball and readily moveable on a pin. On turning the winch, the electrometer becomes, like the conductor, positively electrified; the pith ball C, consequently, becomes repelled by the stem D, and leaves it, raising the index to 90°, if the action of the machine be sufficiently strong.

Exp. (B). Place in one of the holes in the prime conductor, the stem of an artificial feather, formed of fibres of finely-spun glass. On revolving the cylinder, the fibres becoming similarly electrified, repel each other in an extremely beautiful manner.

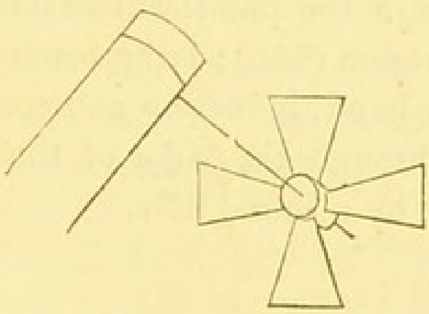
Exp. (C). Suspend from a brass rod, inserted into the conductor of the machine, a plate of copper, about four inches in diameter, and about two inches beneath it, place a second of rather larger size ; on electrifying the conductor, the positive electricity of the upper, renders the lower plate negative by induction, and discharge would ensue, if they were not too far apart. On the lower, place some figures of pith of elder or paper, and on turning the machine, they will begin to dance between the plates, being alternately attracted and repelled by each.



Exp. (D.) Suspend, from a rod on the conductor, the apparatus well known as the electric bells; the two outer bells are suspended by brass chains, whilst the central, with the two clappers, hang from silken strings; the middle bell is connected to the earth by a wire or chain: on turning the cylinder, the bells A and B become positively electrified, and by induction the central one becomes negative; luminous discharge taking place between them, if the electricity be in too high a state of tension. But if the cylinder be slowly revolved, the little brass clappers will become alternately attracted and repelled by the outermost and inner bells, producing a constant ringing as long as the machine is worked.

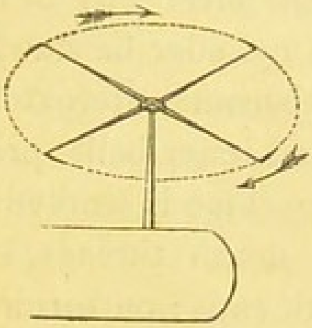
Exp. (E.) Fix to the conductor a dozen threads, — each about eight inches long, tied at both ends; on turning the machine, the threads becoming similarly electrified will repel each other, and as they are fixed at top and bottom, their centres will repel each other, and separating, the threads will represent a skeleton spheroid so long as the machine is turned.

276. If a pointed wire be fixed to the prime conductor, a discharge takes place silently from it, in the form of a luminous pencil of rays, on working the machine; this is accompanied by a brisk current of air, very sensible to the finger, when held near the point.



Exp. (A). Fix four vanes of pastboard into a circular piece of cork furnished with a steel needle as an axle; suspend this from one of the poles (207) of a bar magnet, and on holding it towards the conductor, so that the current of air excited by the discharge from the pointed wires may strike the vanes, the little apparatus will begin to revolve with great rapidity.

The current of air thus set in motion, by discharges from pointed surfaces, is sufficient to react on the wire and cause it to move in an opposite direction to the current, if it be so arranged as to be capable of moving.



Exp. (A). Place the cap of the electrical fly, furnished with four pointed wires bent near their terminations at right angles; on a pivot fixed in one of the holes of the prime conductor. On turning the winch, the wire will rapidly revolve in a direction opposed to the points, as shown by the arrows, exhibiting in the dark a complete circle of light.

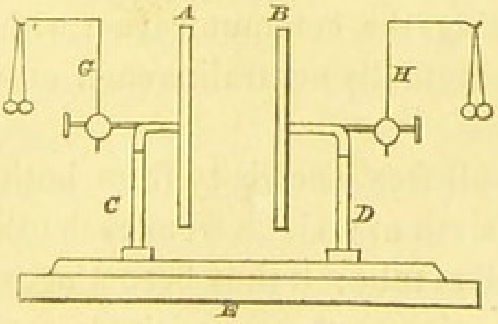
277. The mechanical force of electric discharge is very considerable, providing its effects be concentrated in one particular spot, otherwise it is not very evident.

Exp. (A.) Fill a phial with oil, or other non-conducting fluid, pass through the cork a copper wire bent near its lower end at right angles, so that its point may press against the inside of the glass, and suspend it by the upper end of the wire from the prime conductor. From the machine, the point of the wire in the phial will assume a high state of positive electric tension (256); bring towards it a brass knob, or a knuckle of the hand, induction and consequent discharge will take place through the sides of the glass, which will become perforated by a round hole.

CHAPTER XIII.

ELECTRICITY. CONSEQUENCES OF INDUCTION.

278. When two insulated conducting bodies are differently electrified, and approached towards each other, so as to be within the influence of their mutual attraction (258, b), but not sufficiently near to permit of luminous discharge, no signs of electricity are communicated by either to a pith-ball electrometer connected with them, until the bodies are separated to a considerable distance from each other. The electric fluids are thus said to become *disguised*, or *paralysed*, by their mutual attractive action.



Exp. (A). Let two plates of tinned iron, ab, a foot in diameter, be insulated on varnished glass legs, CD; fixed into pieces of wood moving in a groove in the board E. To the backs of each of these plates is soldered a brass wire, furnished with a binding screw, grasping wires, GH, from each of which is suspended a pith ball electrometer. Now separate A and B from each other, and touch one with an excited piece of glass, the other with excited resin, the pith balls connected with each will diverge, one with negative, the other with positive electricity. Gradually approaching the plates, and as their mutual distance diminish, the pith balls will gradually collapse, until A and B are very near to each other, when they will appear totally unelectrified.

EXP. (B.) The apparatus being in this state, gradually separate A and B, and, in proportion as this is done, the pith balls will diverge as before, proving that the electric states of the plates had not been destroyed by the previous experiment.

279. These phenomenadep end upon a very simple cause, the attraction of the electricity in A being sufficient to draw all that of the opposite kind in B, from the wire H, into that part of the plate opposite it; whilst the electricity in B acts in a similar manner on that in A; and thus, by their mutual attraction the two fluids are collected into those surfaces of the plates nearest each other, and being, by their attractive influence, retained there, become incapable of action on the electrometer: on separating A and B, this attractive influence decreases (258), and the electricity, being diffused over the surfaces of A and B, act upon the electrometer connected with them. The two electric fluids cannot unite by luminous discharge, until A and B are very close to each other, and then, or by making the communication with a curved wire, they unite, and mutually neutralize each other, producing a true discharge.

Next, remove all free electricity from both A and B, bring then within one sixth of an inch from each other, and touch A with an excited glass tube; it thus becoming positively electrified, acts by induction on the electricity in B, attracting its negat and repelling its positive, which, running up the wire H, reaches the pith-balls and causes them to diverge. Touch B with the finger, and the positive electricity thus separated by induction, will escape, leaving B negative; its electrometer cannot diverge, because its negative fluid is retained in the surface opposed to A. Separate A and B, both electrometers will indicate free electricity of an opposite kind in each; again approach them and the pith balls will as before collapse. Then connect A and B, by a curved wire, and the two fluids will rush together, producing a luminous discharge. In this experiment we have the second plate B, becoming negatively electrified through air as a dielectric, and this plate of air is said to be *charged*, its particles, lying between A and B, becoming polarised, and arranged as required by the theory of induction; the latter force being necessarily and solely exerted between contiguous particles.

The plate of air thus becoming charged, may be discharged and reduced to its primitively unelectrified state, in two modes; first, by gradual and silent, secondly, by explosion and sudden discharge. The conditions for producing the first, are fulfilled by merely leaving the instrument (278) exposed to the air for a sufficient space of time, gradually the electricities in the two plates combine, and the separating dielectric air is necessarily discharged; for the second mode, all that is necessary is to connect the plates A and B by means of a curved wire or other conductor, the free electricities then combine, suddenly producing a luminous discharge.

280. Any other dielectric may be substituted for air in these experiments, and if a plate of glass or resin be used, the electricities accumulated in its two surfaces may be increased to a very considerable degree of tension.

Exp. (A.) Place a large pane of glass, about fourteen inches square, between the two plates of the apparatus (278), and bring A and B so near to each other as to tightly grasp the pane. Connect A with the prime conductor of the electric machine, and work the latter so as to render A powerfully positive: this will act by induction through the pane of glass, on the electricity naturally present in B, as before (279), repelling its positive, which, on approaching the hand to the back of B, will produce a series of sparks, or discharges (268). After a certain time, these will cease; then remove the wire connecting A to the prime conductor, and leave it insulated; the plate A will then be charged with positive, and B with negative electricity, both in a state of high tension; connect the two plates by means of a curved wire, and *discharge*, arising from the union of the two electric fluids, results, attended with a vivid flash of light and a loud snap. If, instead using a curved wire, the plates be connected by the fingers of both hands, the same discharge ensues, accompanied by an exceedingly disagreeable and painful sensation, well known as the electric shock.

Exp. (B.) Instead of placing a pane of glass between the two metallic plates, coat it on each side with a piece of tinfoil, leaving about one inch and a half all round uncovered; then on connecting one side with the conductor of the machine, and the other with the earth, the glass dielectric will become charged as before, that side connected with the conductor containing positive, and the other negative electricity.

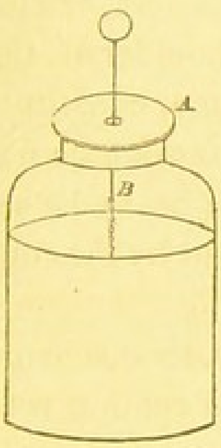
281. The *charge*, thus communicated to the plate of glass, penetrates its substance to a certain distance, as was first pointed out by Mr. Henley.

Exp. (A.) Coat two thin pieces of window-glass on one side only with a piece of tinfoil, considerably smaller than the glasses; place these together, with their uncoated sides in contact. Charge this double plate (280) as before, and then attempt to separate them, they will be found to adhere very tightly together; on pulling them asunder, the naked side of that plate which had been connected with the conductor will be found positively, and that of the other plate negatively electrified.

282. Induction, and subsequent charge, does not become materially modified by the figure of the glass, its thickness

only influencing these actions, and as the plate is a very inconvenient piece of apparatus, glass jars or bottles coated with some conductor, are almost universally substituted for it. This, indeed, was the first arrangement used, forming the celebrated electric or Leyden phial, so called from the place of its discovery, by Cuneus or Muschenbroek, in 1700. Green or white glass answer almost equally well for the construction of electric jars; wide-mouthed glass jars are very convenient, but on account of their expense, common wine-bottles may be very conveniently substituted, provided they are free from air-bubbles, and specks of unvitrified matter.

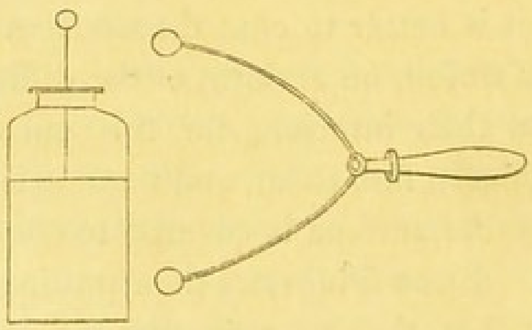
283. The ordinary Leyden phial, or jar, consists of a glass bottle of any size, coated internally and externally with tinfoil to about three inches from its mouth; the latter is closed



by a dry and varnished cork, or wooden disc A. A stout brass wire, furnished with a ball of the same metal, passes through the cover A, and has several thin pieces of wire, or a chain fixed to its end B, so as to touch the inside coating in several places. The knob, thus corresponds to the internal coating. When narrow-mouthed jars or bottles, as the common sixteen ounce phials of white glass (which from their thinness form excellent electric jars,) are used, it is better to coat them internally with brass filings, instead of tinfoil, on account of the difficulty of applying the latter to their interior; for this purpose some thin glue should be poured into them, and the bottle turned slowly round, until its inner surface is covered to about three inches from the mouth. Brass filings are then put in, and the bottle well shaken, so that they may be diffused equally over its surface; on inverting it, those which are in excess will fall out, and t hebottle will be left coated internally, sufficiently well for its intended purposes; some jars should always be provided with hooks, instead of knobs as it is requisite frequently to suspend them to the conductor. To prevent the too rapid deposition of moisture on the uncoated part of the glass, it is a good plan to varnish the jar above the external coating, with a solution of gum-lac in alcohol, or with the common spirit-varnish of the shops; taking care to warm the jars before, and after its application.

284. If the knob of a jar (283) be held about half an inch from the prime conductor, whilst its outside communicates with the earth, a rapid succession of sparks will take place between the knob and conductor, which will continue for some time, and then cease. The jar will now be *charged*, its inside, containing positive and its outside coating, negative electricity; their union being prevented by the interposed glass, unless the tension of the electricity be considerable, in which case, discharge often ensues through the glass, which then becomes perforated, and the jar rendered useless, or else by passing over the surface of the uncoated shoulder of the bottle in the form a bluish lambent brush of flame, constituting the spontaneous discharge. If the electric tension be not sufficient to produce these phenomena, and the bottle be set aside, gradually its electricity becomes neutralized by the conducting action of the surrounding atmosphere.

285. When an electric jar is charged (284), its discharge may be effected, either by grasping its external coating with



one hand, and touching the knob with the other, in which case the person who performs the experiment, experiences the peculiar and painful sensation, termed " the shock" in his arms, and if the jars be large, through his shoulders and chest. A charged jar whose outside contains negative and inside positive electricity, is said to be positively electrified; and to be negatively electrified, when the electricity of its internal coating is of that kind.

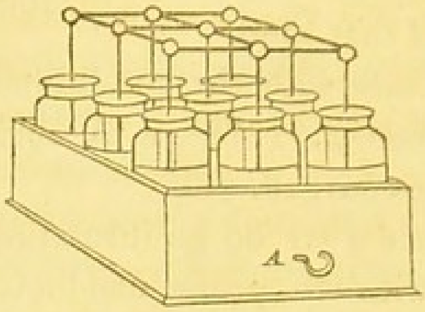
286. In accordance with the conditions of the induction and disguise of electricity (278), it is obvious that an insulated jar cannot be charged.

Exp. (A.) Place a jar on an insulating support, with its knob in contact with the prime conductor, on working the machine for some time, and examining the jar, it will be found to be almost destitute of any electric charge; for on connecting its outside and inside coating, by means of the discharging rod (285), no discharge takes place.

Exp. (B.) Place the jar in the same position, and whilst the machine is in action, approach the finger to the outside coating, vivid sparks will pass towards it, arising from the positive electricity belonging to the outside of the jar, uniting with the negative in the finger. After a certain time these sparks will cease, and on approaching the discharging rod to the jar (285), the flash of light and vivid snap that ensue, prove that the jar has received a considerable charge. If the knob of a second jar be substituted for the finger, it will become charged by the electricity, repelled from the outside of the first jar; this mode of charging is termed, by the French, "charger en cascade."

287. The *charge* of an electric jar varies, *cæteris paribus*, with the extent of coated surface; and on this account, very large jars have been constructed. These, however, have several inconveniences, and among them may be mentioned, the necessary thickness of the glass when the jars are very large, preventing induction to any great intensity taking place through them. On this account, several small jars coated in the usual manner (283), are placed in a box lined with tinfoil, or other good conductor, so as to connect their outsides, whilst their knobs, and consequently their insides, are connected by brass rods; the whole constituting the

electric battery. As the interior of all the jars communicate,



they may be charged as a single jar (284), their exteriors being connected with the earth.

288. In charging a battery, its interior is connected by means of a wire or chain with the prime conductor (260), and its exterior connected with the earth; and for the purpose of tracing the progress of the charge, the quadrant electrometer (275, A) is fixed in one of the holes of the prime conductor. On turning the machine, the positive electricity accumulating in the inside of the battery becomes disguised (278), by the inductive action of the outside coating, and consequently does not act on the electrometer (279); but in proportion as the electricity ceases to be retained by this action and accumulates in the conductor, it acts on the electrometer and raises its index, which, when the battery has attained its utmost charge, seldom rises above 40° or 50°. The battery may be discharged like a single jar, by connecting its outside and inside, by means of a discharging rod (285), or a chain. Great care should be taken in this operation to avoid passing any of the electricity through the body, as the shock from a powerful battery might be attended with serious consequences.

289. After a large jar or battery has been discharged, its two surfaces should be left connected for some time, as a *residual charge*, arising from the return of the electricity which had penetrated the substance of the dielectric (281) to the coatings, often takes place, and may give a severe shock to a person touching the battery without this precaution.

290. When the two surfaces of a charged jar are connected

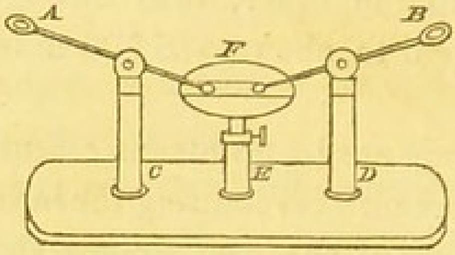
by means of the discharging rod (285), or a long metallic wire, the two electric fluids rush together and unite with an enormous velocity; in fact, even with the largest circuit yet employed, their union appears to be absolutely instantaneous. From a series of very beautiful experiments performed by Professor Wheatstone,* it appears probable that the electric fluids, in passing through a conducting wire from one side of a charged jar to the other, rush through the conductor with a velocity equal to about 576,000 miles in a second of time.

291. The coatings are by no means essential to an electric jar; they act only as surfaces limiting the inductive action, the *charge* itself, residing as has been already shown, in theglass. This may be further proved, by providing a wide-mouthed glass jar with moveable coatings; charging it (284), and removing the coatings, these will be found unelectrified, and on replacing them by another pair, the jar may be discharged, the flash accompanying which act, will be found scarcely less than that of a jar whose original coatings have been retained. A jar may also be charged without metallic coatings; for if a glass tumbler be grasped by the hand, and its mouth held over a pointed wire, fixed on the prime conductor of a machine in action, it will become charged, and on fitting a pair of coatings to it, it may be discharged like a common jar. If, instead of discharging it, it be inverted on a table over some light pith-balls, these will be attracted by its internal surface in a very curious manner, and the discharge will become gradually effected. The coating, as might be from these facts expected, needs not be continuous, it may consist of a number of separate pieces of tinfoil fixed at a small distance from each other. Jars thus coated, are termed *diamond jars*, from the brilliant scintillations appearing on their surfaces when they are discharged.

292. When the union of the two electric fluids, necessary for

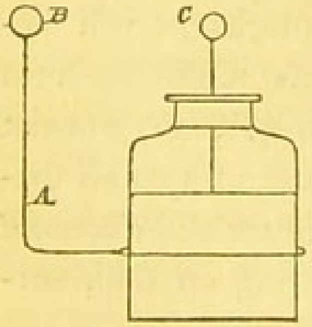
* Phil. Transactions, 1834, p. 591.

the discharge of a jar, is effected by various conductors connecting the two surfaces, the charge is said to pass through them, and very important and interesting mechanical and chemical effects, are thus produced. For the purpose of passing the charge through different bodies, a very convenient piece of apparatus, called the *universal discharger*, is employed; this consists of two brass wires, A B, terminating in points, to which



balls are screwed, and furnished with a ball and socket joint, so that they are moveable in any direction on the tops of the glass supports C D. A hollow wooden support, E, is fixed midway between them, into this is screwed a small wooden table having a slip of ivory inlaid on its surface; on which any substance to be subjected to the action of the current is placed. A small press is sometimes placed in E, instead of the table F.

293. The following experiments, requiring for their performance a charged jar, exposing about a square foot of coated surface, will illustrate exceedingly well the general properties of accumulated electricity.



(A.) Fix to the outside coating of a jar a curved wire, A, terminated by a metallic ball, and rising to the same height as the knob of the jar. Charge the latter, and hang by a silken thread midway between B and C, a cork ball, suspended by a piece of silk thread ; immediately the ball will become attracted by C, then repelled to B, again attracted, and so on, continuing this active motion until the jar is discharged.

(B.) Insulate (235) a charged electric jar (284), and connect the electric bells (275) to its knob. They will remain at rest, until the outside of the jar is placed in connexion with the ground, or with the chain connected to the middle bell, when the clappers will be set in active motion, and will continue striking the bells until the jar is discharged.

(C.) Place, on the table of the universal discharger (292), some gunpowder, unscrew the knobs from the wires AB, and place their points in the powder, and about half an inch from each other. Connect the outside of the charged jar with A, by means of a chain, and touch B with its knob, the *charge* will pass through the powder, and scatter it in all directions without inflaming it. An effect probably arising from the enormous velocity (290), with which electricity traverses a circuit, not allowing sufficient time to produce the effects of combustion.

(D.) Place some more gunpowder on the table of the discharger, and arrange the apparatus as before; connect the outside of a charged jar with A, by means of a piece of thick *string soaked in water*, instead of a chain; touch B with the knob, the gunpowder will be instantly inflamed. The action of the wet string appears to favour the combustion, by impeding the velocity with which the electricity traverses the powder, and thus allowing time for the production of its calorific effects.

(E.) Tie some tow loosely over one of the knobs of the discharging rod (285), and dip it in powdered resin; place the naked knob in contact with the outside of a charged jar, and bring the other in contact with the ball; discharge will take place, and the resin will burst into flame.

(F.) Place between the knobs of the universal discharger (292), a thick and dry card, discharge a jar through it; and a perforation will be produced, the card being *burred* outwards in both directions, as though the force producing it had acted from the centre of the thickness of the card outwards.

(G.) Colour a card with vermilion, unscrew the balls from the universal discharger, and place the points on opposite sides of the card, one about half an inch above the other; discharge a jar through them. The card will be always perforated at the point opposite to the wire, connected with the negative side (284) of the jar; a black line of reduced mercury, will be found extending from the point where the positive wire, touches the card, to the place of perforation. This curious result arises from the great facility with which positive electricity passes through air, as compared to negative; and on repeating this experiment *in vacuo*, the perforation always takes place at a point *intermediate* between the two wires.

294. When electricity is accumulated in large jars, or, still better, in a series of jars constituting the battery, we are capable of producing results which simulate the effects of lightning; and may be considered as bearing the same relation to the area in which they are exhibited, as the former does to the great theatre of nature, in which its no less grand than awful phenomena are displayed. The mechanical effects, accompanying the discharge of an electric battery, are extremely interesting, but the calorific phenomena it produces are still more so. In these experiments the universal discharger should always be used to apply, and the quadrant electrometer (275) to afford, a comparative measure of the charge employed.

(A.) Place a sheet of white paper on the table, and let a fine iron chain about two feet long, connected with the wires AB of the discharger (292), lie upon it. Transmit the charge of about six jars, each presenting about a foot of coated surface, through the chain;—on removing the latter from the paper, its outline will be observed marked upon it, with a deep stain at each link. The paper is often burnt through, in places if the charge be sufficiently powerful.

(B). Tie on one end of each rod of the discharger (292), the end of a piece of fine steel wire,* about four inches long,

* The *watch-pendulum wire* is best for this purpose, that sold as number 32, readily undergoing combustion by a very low charge.

and discharge the battery through it. The wire will be burnt with a vivid flash of light, becoming converted into oxide, which is dispersed in all directions.

(C.) Place a slip of gold-leaf between two pieces of paper, allowing its end to project, and press the whole firmly together by means of the little press of the universal discharger; let its rods AB (292) touch the projecting portions of the gold-leaf, and transmit the shock of a battery through the apparatus. On removing the paper from the press, it will be found stained of a deep purple hue from the oxydized gold, the metal being entirely converted into oxide by the discharge.

(D.) If, instead of using paper, the gold-leaf be pressed between two plates of glass, the latter will be generally broken to pieces, and the gold forced into their substance by the force of the explosion.

295. The electric discharge is capable of communicating transient phosphorescent properties to various bodies over which it passes; thus sugar, fluor spar, and carbonate of lime, continue to emit a green light for some seconds after the charge has passed over their surface.

296. As we have seen that electric induction takes place with very great facility through highly-rarefied air (269), we can readily understand the rationale of the Leyden vacuum; this consists merely of an electric jar coated as usual externally, its interior being exhausted of air, by means of the air-pump (152), and having a point dipping into its inside, and connected externally with a knob. This apparatus may be used like the common electric jar, induction and discharge readily taking place from the point over its whole internal surface. On charging and discharging it in a dark room, the point of the wire in its inside becomes beautifully illuminated with a *star* or *pencil* of rays (267), according as the electricity happens to be of the positive or negative character.

297. The opposite electric states of a charged jar, may be beautifully demonstrated by means of the well-known figures

of Leichtenberg.* To show these, make the resinous cake of an electrophorus (254) dry and warm; draw lines on it with the knob of a positively charged jar, and sift over these places a mixture of sulphur and red-lead; on inclining the plate, to allow the excess of the powders to fall off, every line marked by the knob of the jar will be observed covered with the sulphur, whilst the minium will be dispersed. On wiping the plate and drawing figures with the outside of the jar, the sulphur will be dispersed, and the minium collected in a very elegant manner on the lines described by the outside of the jar. The rationale of this experiment is very obvious, the sulphur becomes negatively and the red-lead positively, electrified by the friction to which they are necessarily exposed, and on allowing the mixture to fall on surfaces possessing one or the other electricity in a free state, the sulphur will be collected on the positive and the minium on the negative portions of the plate, according to the well-known law of electric attraction (233).

298. By means of the action of induction causing the *disguised or paralyzed state* (278) of electricity, we are enabled to detect very minute traces of free electric fluid with facility; instruments arranged for this purpose are called *condensers.* To illustrate their use, touch the prime conductor of an electric machine in weak action, with a disc of metal furnished with a glass handle, as the cover of the electrophorus (254), and bring it towards the cap of an electrometer, the gold leaves will scarcely be moved. Then touch the conductor once more with the disc, holding beneath and parallel to it, at the distance of about a quarter of an inch, a second disc of metal, but *uninsulated.* Remove them from the conductor, and touch the cap of the electrometer with the insulated plate, take away the other plate, and immediately the gold-leaves will diverge to a considerable distance from each other. In this experiment, the conductor being

* Nov. Comment. Soc. Götting., p. 169. 1777.

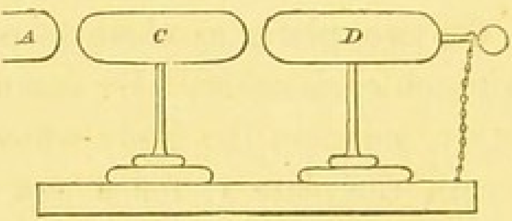
weakly charged, the plate of the electrophorus employed can only remove a portion of electricity equal to its own surface, a quantity far too small to act upon the electrometer; but on repeating the experiment, with a second plate held parallel to the first, induction comes into play, the electricity which first enters the insulated plate becomes *latent* or *disguised*, a fresh portion enters, and so on, until the plate of air confined between the two discs of metal becomes charged (279). On then separating them, the coercing force holding the electricity latent, becomes removed and the absorbed electric fluid readily acts on the electrometer. The most convenient form of the condenser is the apparatus, used in the beginning of this chapter to illustrate the phenomena of induction (278). To use this for a condenser, remove the cork-ball electrometers, and connect one of the plates, as A, with a gold-leaf electrometer (239), by means of a wire. Connect the other plate with the earth by means of a piece of chain or wire, then bring the two plates as close as possible without allowing them to touch each other. By means of a wire, or by absolute contact, connect the body whose electricity is to be examined with the plate A, for a few seconds; then remove it; quickly separate B from A, and instantly the electricity left free in A, will cause the gold leaves of the electrometer to diverge.

In this manner, the smallest traces of free electricity can be readily detected. As it is difficult to place the plates of the condenser as close as is necessary, without their accidental contact often ensuing, it is usual to cover their opposed surfaces with a thin layer of resinous varnish, as a solution of gum-lac in alcohol. When plates thus prepared are used, the layer of resin becomes the charged *dielectric*, instead of the thin plate of air.

299. When a large jar, or battery is discharged by means of a discharging rod without a glass handle, a slight shock is often felt by the person holding it, although he forms no part of the direct circuit. This arises from what has been

termed the *lateral explosion*, or more appropriately by Lord Mahon,* the returning shock, and arises from the accumulated electricity not passing through the conducting medium in a single instant of time, although its rapidity is so excessive (290); it therefore acts by induction on the electricities naturally present in the substance in contact with the conductor, as the hand; it effects their separation and their recombination, the instant the discharge of the jar is completed, producing the slight shock experienced. The lateral explosion is exhibited in the following experiments.

(A.) Charge a jar, and place on the table, with one end in contact with the outside coating, a piece of brass chain. Discharge the jar by means of the discharging rod, and the instant the discharge occurs, the chain, although not forming any part of the circuit, will be illuminated by a spark appearing between each link.



(B.) Let an insulated conductor C, be placed about three inches from the end of the prime conductor A, of an electric machine. A conductor connected with the earth by means of a chain, as D, is placed about a quarter of an inch from C. Then A, being positively electrified, decomposes the electricity in C, repelling *its positive* to D, whence it escapes to the earth, so that C is left in a negative state. On discharging A, by touching it with the fingers, a vivid spark appears between D and C; and C is then found to be in its natural electric state.

300. Hitherto, we have considered that negative and positive electricity possess the same properties with regard to

* Principles of Electricity, p. 69. London, 1751.

conduction and insulation; differing in the appearance of their luminous discharge, the one being accompanied by a star, and the other by a pencil of light (267). A remarkable circumstance has been lately observed, which tends to indicate the probability of the existence of some more important difference between them, instanced in certain bodies being capable of conducting one fluid, and insulating the other, when they are in a state of *extremely weak tension*. These bodies are termed unipolar; among them, the flames of alcohol, coal-gas, and sulphur appear to conduct positive electricity, whilst the flame of phosphorus, dry albumen, ivory, and dry soap, conduct negative electricity. Of an approach to this curious class of bodies we have an instance in atmospheric air, which would appear to allow the discharge of positive, to take place quicker than negative electricity (293, G), although Professor Belli has stated the contrary to be the fact.*

301. Good conductors, and non-conductors pass into each other by insensible grades, and indeed rather differ from each other, in one insulating better or worse than another, as they all offer more or less opposition to discharge taking place through them; and at length, such a point of indifference to the discharge of electricity is met with, that bodies are known which allow discharge to take place through them in one direction, and prevent it in another, as in the so-called unipolar bodies discovered by Ermann. Many non-conductors insulate when cold, and conduct when heated red-hot, as glass; others do not acquire their conducting power until they are fused, as is the case with resinous electrics, which allow discharge to take place through them when they are fused, a circumstance first, I believe, mentioned by Cavallo.†

* Poggendorff, Annalen, t. xl. p. 73.

† Treatise on Electricity, p. 306. London, 1777.

CHAPTER XIV.

ATMOSPHERIC ELECTRICITY.

Atmospheric Electroscopes, 302. *Diurnal variation of Aerial Electricity*, 304—*Monthly variation of*, 305—*Causes modifying*, 306—*Collected by the Kite*, 308—*and by arrows*, 309. *Sources of Aerial Electricity* 310. *Lightning*, 311. *Paratonnerres*, 313. *Illustrative Experiments*, 314. *Feu de St. Elm*, 315. *Aurora Boreales*, 316.

302. THE atmospheric medium, by whichwe are surrounded, contains not only *combined* electricity, like every other form of matter, but also a considerable quantity in a free and uncombined state; sometimes of one kind, sometimes of the other; but as a general rule it is always of an opposite kind to that of the earth. Different layers, or strata of the atmosphere, placed only at small distances from each other, are frequently found to be in different electric states.

303. Various pieces of apparatus have been contrived to facilitate an examination of the electric state of the atmosphere, consisting in general of poles elevated about thirty feet into the air; provided with a metallic point at their upper, and insulated at their lower ends. The electric bells (275 D), being frequently suspended from a conductor in contact with such pieces of apparatus, so that by their ringing, they may indicate the presence of free electricity in the conductor.* A long fishing-rod, raised above the highest part of the house, and provided with an insulating conducting wire, furnishes a very convenient apparatus for occasional observations.† The apparatus used by Saussure, was merely a well-insulated

* Phil. Trans. 1792. † Cavallo, p. 370.

electrometer, provided with a conducting wire about three feet in length, to absorb the electricity from the air.

304. By means of any of these pieces of apparatus, we can readily arrive at a knowledge of the electric state of those portions of the atmosphere nearest the earth. In clear weather, indications of free positive electricity are always to be met with in the atmosphere; this is weak before sunrise, becoming stronger as the sun passes the horizon, and soon afterwards gains its greatest state of intensity; it then rapidly diminishes, and regains its *minimun* state some hours before sunset, after which it once more increases, and gains its second *maximum* state, which then decreases until the following morning.*

305. M. Schubler of Stuttgard, to whom we owe the above observations, has remarked that the atmospheric electricity increases from July to January, and then decreases. It is also much more intense in winter than in summer, and appears to increase, as the cold increases.

306. Among the causes modifying the electric state of the atmosphere must be ranked its hygrometric state, as well as probably, the nature of the effluvia which may become volatilised in any given locality. Thus, Saussure has observed that its intensity is much more considerable in elevated and isolated places, than in narrow and confined situations; it is nearly absent in houses, under lofty trees, in narrow courts and alleys, and in inclosed places. In crowded cities it is most intense in the squares, and upon the bridges. In some places the most intensely electric state of the atmosphere appears to be that, in which large clouds, or dense fogs, are suspended in the air at short distances above the surface of the earth; these appear to act as conductors of the electricity from the upper regions.

307. Cavallo ascertained, from a set of experiments performed at Islington in 1776, that the air always contains free *positive* electricity, except when influenced by heavy clouds

* Becquerel, Traité, t. iv. p. 84.

near the zenith. This electricity, he found to be strongest in fogs and during frosty weather, being weakest in hot weather, and just previous to a shower of rain; and to increase in proportion as the instrument used is raised to a greater elevation. This indeed necessarily happens, for as the earth's surface is, *cæteris paribus*, always negatively electrified, a continual but gradual combination of its electricity with that of the air is constantly taking place at its surface, so that no free positive electricity can be detected within four feet of the surface of the earth.

Mr. Crosse, of Bromfield, collects and examines the atmospheric electricity, by means of wires, insulated and supported by poles and by the trees in his park. When these conductors are about one third of a mile in length, he has frequently succeeded in collecting sufficient electricity, to charge and discharge a battery of fifty jars, containing seventy-three square feet of coated surface, twenty times in a minute, accompanied by reports as loud as those of a cannon.*

308. The first satisfactory attempt to collect the electricity of the upper regions of the air, was made by Dr. Franklin in North America, in 1752, although it must be observed that a short time previously, Dalibard had by means of a long pointed conductor, raised in Marly-la-Ville, succeeded in obtaining vivid sparks of atmospheric electricity. Dr. Franklin raised into the atmosphere a kite, formed by stretching a silk handkerchief across two rods of light wood, and with this, when the string had been rendered sufficiently moist by the falling rain to conduct electricity, he obtained a copious succession of sparks, from a key fastened to the end of the string. Subsequently, M. Romas, in France, by increasing the length of the string, obtained flashes of electric light from his apparatus, ten feet in length, accompanied by a report as loud as that of a pistol. Shortly afterwards Professor Richman, of St. Petersburg, was struck dead by

* Sturgeon's Journal. Vol. i. p. 139.

a discharge from an apparatus, similar to that of M. Dalibard, with which he was experimenting.

Cavallo, in 1777, raised an electric kite repeatedly in the neighbourhood of London, and obtained an enormous quantity of electricity; he found that the electricity frequently changed its character, as the kite passed through different aerial layers or strata.

309. Perhaps the readiest mode of investigating the electric state of the upper regions, is by means of the apparatus used by MM. Becquerel and Breschet, on the great St. Bernard.* These gentlemen fixed one end of a cord covered with tinsel, about ninety yards in length, to the cap of an electrometer, and tying the other to an arrow, they projected it, with the aid of a bow into the air, and they found that the gold-leaves diverged in proportion as the arrow ascended into the atmosphere.

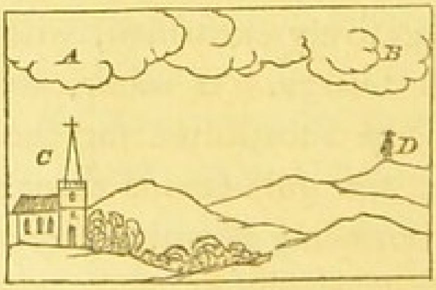
310. The probable cause of the free electricity in the air has been referred to various sources; the phenomena of animal and vegetable life, as well as chemical action, have been called in to explain its origin. Among others, the evaporation of water, and other fluids, constantly taking place on the earth's surface, may certainly be regarded as one of the sources of atmospheric electricity. The evolution of electricity by evaporation, may be readily proved by placing on the cap of a gold-leaf electrometer (239) a small metallic cup containing water, in which some common salt has been dissolved. On dropping into it a piece of hot cinder, the vapour will arise copiously and carry off positive electricity, leaving the cup negatively electrified, with which electricity the gold-leaves will diverge. If water, containing a minute portion of an acid, be substituted for the weak brine, the reverse will occur, the gold-leaves diverging with positive electricity, the vapour being negatively electrified.

311. The clouds, consisting of immense masses of aqueous

* Traité de l'Electricité et du Magnétisme. t. iv. p. 110.

vapour, are tolerably good conductors of electricity, and consequently, contain a considerable quantity of the latter in a free state. Two clouds, being in different electric states, act upon each other through the particles of the intervening dielectric, or air; like the inducing surfaces or metallic coatings of a charged jar (280), and when sufficiently near to each other, *discharge* occurs, producing the vivid flash well known as lightning, generally accompanied by the loud reverberated sound of thunder. When, on the other hand, induction, and consequent *charge* takes place through the air, between an electrified cloud and the earth, an explosion or *discharge* ensues, when the intervening particles of the dielectric are so arranged as to admit of its occurring; producing a second, and much dreaded form of lightning. This mode of establishing an equilibrium between two oppositely electrified bodies, often ensues through the medium of the nearest most prominent conductor, which, if a tree, is often riven in sunder; if a building, as a church, is frequently dashed in pieces; and if an animal, too often severely injured or even killed.

312. Several instances have occurred of the fatal effects of a tempest, having been exerted on animals at a considerable distance from the spot where the most serious effects have taken place, and where the violence of the lightning appeared to have been chiefly exerted. This will readily admit of explanation, on the supposition of a lateral explosion or returning shock (299) having occurred. Thus, if AB be



a large cloud, positively electrified, approaching at its end, A, within striking distance of the church-steeple C, the extremity

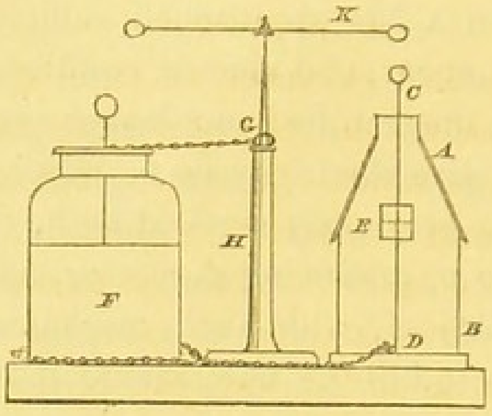
B, will, by its inductive action, decompose the electricities present in any object at D, as a traveller for example, repelling the positive to the earth, and leaving him in a negative state. When A has approached sufficiently near to C, an explosion will occur, and electric equilibrium will ensue. B being thus left unelectrified, no longer exerts a coercing force on the negative electricity in D, which, attracting the positive electricity previously repelled by B, causes it to rush with violence into D, producing *discharge*, and a restoration of electric equilibrium, with such mechanical force, however, as too often to kill the unfortunate individual situated at D.*

313. Science, and mankind generally, must ever remain debtors to the ingenuity of Dr. Franklin, for proposing, at least, a partial protection against these dreaded effects of the tempest, in the invention of the *paratonnerre*, or lightning rod. These consist of metallic conductors, of sufficient thickness, usually fixed against the sides of the building they are destined to protect, their upper extremity extending some feet above it, and terminates in a point, which is best constructed of some metal not liable to oxydation. The lower end is buried in the earth, to the depth of a few feet. For ships, flexible paratonnerres, composed of copper chain, or slips of that metal, are fixed to the masts, and reaching from their highest points to the outside of the keel of the vessel, so as to conduct the electricity harmlessly to the water in which the vessel floats. Whatever form is used, one general precaution is necessary, *that all and every portion of the paratonnerre should be as perfectly continuous as possible*, for wherever a break or interruption occurs, the electric fluid, in rushing from one portion to another, is liable to produce the very danger which these instruments are intended to avert.

314. To illustrate some of these positions, the thunder-house, as it is termed, was invented by Dr. Franklin: A B

* See Traité Elémentaire de Physique, par M. L'Abbé Hauy, p. 434. Paris, 1806.

is a piece of hard dry wood, cut into the shape of the gab'e end of a house, with a brass rod, terminating in a ball at C,



fixed against its side, and terminating at D in a hook. At E this conductor is interrupted by a block of wood, fitting loosely into a cavity made to receive it, having a wire fixed across it; so that when E is fitted in its place, as in the figure, the conductor CD is perfect; but when placed in the opposite direction, as shown by the dotted line, the paratonnerre CD is interrupted in its centre.

Exp. (A.) Charge the jar F; connect its outside with the hook at the end of D, and its knob with the pointed wire supported on its *insulating* stand H, and bearing on its apex the brass rod K, terminating in balls, and moving on it in any direction, as on a pivot. Place the window E in its place, so that the brass conductor may be continuous, and cause K to revolve, so that one of the balls terminating it may pass within half an inch of C. The jar will be discharged, and the window E remain unmoved.

(B.) Repeat the last experiment, with the window E, placed so that its wire may be at right angles to the axis of the wire CD. On discharging the jar as before (A), the effects of the explosion will be exerted on E, and will project it with violence, from the cavity into which it fits.

(C.) Let things be arranged as in Exp. (B), but remove the knob on C, and leave the paratonnerre pointed. On allowing K to revolve, the jar will be *silently* discharged.

The electric current, during this gradual discharge by the point, never acquiring sufficient tension to act energetically on E, although it was displaced with violence when D terminated in a knob.

(D.) The protecting influence of pointed conductors is more strikingly shown by the electrical toy, called the powder magazine, in which the interrupted portion of the conductor reposes in a mass of gunpowder, placed in a wooden model of a house. If the jar be discharged whilst the paratonnerre terminates in a point, the powder is unaffected; but if a knob be screwed on, the discharge explodes the powder, and blows the model to pieces. In repeating this experiment, a piece of wet string should be used to connect the jar with the base of the paratonnerre, for reasons already mentioned (293 D).

315. The well-known meteoric appearances so frequent on the pointed masts of shipping, known as Castor and Pollux, the feu de St. Elm of the French, and Elmsfeuer of the Germans, appear to depend upon the slow discharge of atmospheric electricity by the pointed masts of the vessel.

316. The beautiful aurora borealis, so frequent in the north of Europe, and of late years not of unfrequent occurrence in the neighbourhood of the metropolis, depends, in all probability, on the passage of electricity through an highly rarefied medium. From the calculations of Mr. Cavendish, it is probable that the aurora usually appears at an elevation of about seventy-one English miles above the earth's surface; at which elevation the atmosphere must be of but $\frac{1}{148,567}$ times the density of that at the earth's surface, a degree of rarefaction far above that afforded by our best air-pumps. As electricity is diffused in a quantity nearly proportionate to the elevation above the earth's surface, it appears very probable, that under favorable circumstances, it would appear luminous to us, in the vast regions of rarefied air terminating our atmosphere, in a manner analogous to that in which it appears on an infinitely smaller

scale in an air-pump vacuum (269). When the discharge of a large jar is effected through a long tube filled with rarefied air, it appears luminous, not in flashes, like the artificial aurora (269), but in a condensed form, like a ball of fire, falling through the tubes; very closely imitating in appearance that of some other meteors, well known as *falling* or *shooting stars*.

CHAPTER XV.

ELECTRICITY EXCITED BY CHEMICAL ACTION.

(GALVANISM, OR VOLATISM.)

Apparent Excitation of Electricity by Contact, 317—*depending on Chemical Action,* 318. *Electric state of Combined Proximate Elements,* 319. *Table of Simple Bodies,* 320. *Simple Pair of Plates,* 321. *Electromotors,* 322-4—*excited by Saline Solutions,* 325—*furnished with Permeable Diaphragms,* 326—*Daniell's arrangement,* 327. *Electricity excited by the action of Fluids on one Metal,* 328. *Voltaic Pile or Battery,* 330—*different arrangements of,* 332—*Shock from,* 335 —*Luminous and Calorific Effects of,* 336-8—*Refrigerating Effects of,* 339. *Electro-chemical Decomposition or Electro-lysis,* 340—*definite Nature of,* 344. *Electrodes,* 341-3 —*Electrolytes,* 345-7. *Quantity and Intensity,* 348. *Volta-electrometer, Polarization of Electrodes,* 349. *Necessary Conducting Nature of Circuit,* 350. *Decomposition by single pair of Plates,* 351 —*by Electricity from Electric Machine,* 352. *Electricity excited by Chemical Combination,* 353. *Dry Piles of De Luc and Zamboni,* 354.

317. It has been already mentioned, that two plates of glass, when pressed together and suddenly separated, assume opposite electric states (343). The same thing occurs when two discs of different metals are similarly treated. To demonstrate this, take a plate of copper and one of zinc, each about four inches in diameter, and furnished with a glass handle fixed in its centre; connect a gold-leaf electrometer (239) with the plate A of the condenser (298), allowing B to be connected with the earth; press the copper

and zinc plates together, holding them by their insulating handles; suddenly separate and apply one of them to the plate A of the condenser; again press them together, having previously touched them with the finger to restore their electric equilibrium, and reapply the same plate to the condenser. Repeat this about six times, then draw back the uninsulated plate B, (298), and the gold leaves of the electrometer will diverge with *positive* electricity if the zinc, and with *negative*, if the copper plate has been applied to the condenser.

318. The development of free positive in the zinc, and of free negative electricity in the copper plate, was attributed by the illustrious discoverer of the fact, Volta, to a peculiar electromotive force, under which, metals, by simple contact, tend to assume opposite electric states. This theory has now but few supporters, except the celebrated Professor Pfaff of Kiel, in consequence of the mass of evidence that has been opposed to it by Fabroni, De la Rive, and our illustrious countryman, Faraday, to whom we are so largely indebted, in this branch of science. These philosophers have very satisfactorily proved, that whenever electricity is developed during metallic contact, it is owing to some chemical action undergone by the most readily oxydizable metal. So rigorously has this been demonstrated, that it may be stated as a general law, *that no chemical action occurs, unaccompanied by disturbance of electric equilibrium, and consequent development of free electricity.*

319. In every chemical combination, whether saline, haloid, or of still more complex nature, the elements, both proximate and ultimate, appear to be held together by their being in opposite electric states, and on their separation they are found to possess, *cæteris paribus*, a certain quantity of free electricity of low tension. So general is this fact, that the discoveries of Dr. Faraday have certainly very closely pointed out the probability of chemical affinity being after all but a modification of electric attraction; an opinion previously

adopted, with some limitation, by Davy, Berzelius, and others no less deservedly celebrated in this branch of experimental science.

320. Among the ultimate elements which chemistry has made us acquainted with, there are twenty-two which are characterized by their electro-negative, and thirty-two by their electro-positive state in relation to each other.

I. Electro-negative.

Oxygen	Fluorine	Tungsten
Hydrogen	Carbon	Antimony
Nitrogen	Boron	Tellurium
Sulphur	Silicon	Titanium
Phosphorus	Selenium	Tantalium
Chlorine	Arsenic	Vanadium (?)
Bromine	Chrome	
Iodine	Molybdenum	

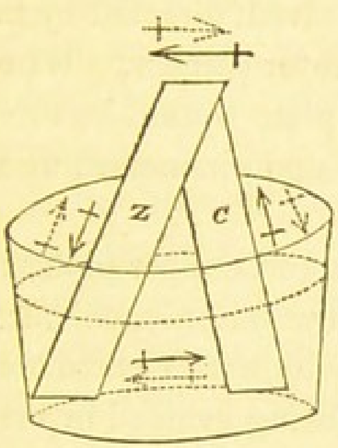
II. Electro-positive.

Gold	Tin	Yttrium
Platina	Lead	Glucinium
Iridium	Cadmium	Aluminium
Osmium	Zinc	Magnesium
Palladium	Nickel	Calcium
Rhodium	Cobalt	Strontium
Silver	Iron	Barium
Mercury	Manganese	Lithium
Copper	Lantanium (?)	Sodium
Uranium	Cerium	Potassium.
Bismuth	Zirconium	

These substances are, it must be remembered, negative or positive only in relation to each other, and their mutual chemical affinities appear to be in the ratio of the intensity of the difference of their comparative electric states. Thus potassium has the greatest affinity for oxygen of any other substance in nature, and, accordingly we find that, whilst the former is in its combinations powerfully positive, the latter is as energetically negative. In the list of negative bodies every element is to be egarded as negative to all below, and positive to all above it in the list: thus hydrogen is negative with regard to nitrogen, but positive with regard to oxygen; and thus, when water is decomposed by an electric current (321), the hydrogen assumes the positive and oxygen the negative electric state. A similar observation applies to the list of electro-positive elements.

321. Let a piece of zinc be amalgamated by immersing it in a little dilute sulphuric acid, and rubbing a few globules of mercury over it with a piece of cork. Fill a glass with a mixture of one part sulphuric acid and ten of water, and place the amalgamated zinc in it. No chemical action or disturbance of electric equilibrium will take place. Immerse in the fluid a rod of any metal standing above zinc in the list (320), as copper; no obvious action will occur until it touches the surface of the zinc, when in an instant a torrent of bubbles from the decomposed water, is evolved from the copper, as though it were undergoing solution. This, however, is not the case, for the zinc is alone dissolved, and consequently mere chemistry is incapable of affording a satisfactory solution to this phenomenon. From the facts already stated we see that the copper and zinc, being placed in contact, assume opposite electric states, from the chemical action of the fluid in which they are immersed. Their electric state increases in tension sufficient to cause the zinc to become so energetically *positive*, as to decompose the water and unite with the negative oxygen, forming oxide of zinc, repelling the positive hydrogen as bodies similarly electrified repel each other (233), this is attracted by the *negative* copper plate; at the surface of which it gives up its free positive electricity, and is evolved in the state of gas. The zinc and copper being thus restored to a state of equilibrium, chemical action again takes place, causing this constant transfer of positive electricity from the zinc through the fluid to the copper, back to the zinc, and so on; whilst a current of negative electricity passes in the opposite direc-

tion. The metals need not be in actual contact in the fluid, for if connected by a conductor out of the fluid the same effects take place.



This conductor may be a wire, or be constituted by the plates themselves, by so inclining them that they may lean against each other, as in the marginal figure, where c is the copper and z the zinc plate; the dotted arrows representing the direction of the *negative*, and the entire ones that of the *positive* current.

That such currents do really exist will presently be shown to be beyond a doubt. As a tolerably satisfactory proof, however, the well-known calorific effects (294) of electricity may be observed by separating the plates cz at their upper part, and connecting them by a piece of very fine platina wire, half an inch in length; this, if the plates be about four inches long and two broad, will become brilliantly ignited, from the electric discharge (280) taking place through it, as long as chemical action continues. In repeating this experiment, ordinary rolled zinc may be substituted for the amalgamated metal, but the phenomena described will be masked by chemical action ensuing at the zinc surface.

322. The electricity thus evolved, although weak in intensity, is considerable in quantity; and for many important experiments a pair of zinc and copper plates, excited by dilute sulphuric acid, are very valuable sources of electricity. These *electromotors*, as they are termed, are best made by placing a piece of sheet copper, a foot long and six inches wide, having a copper wire for a conductor soldered to it, in the inside of an earthern jar; a piece of sheet zinc, nine inches long and six wide, furnished with a similar conductor, is rolled into a cylindrical form and covered loosely with a fold of

linen, so that when placed in the jar, metallic contact between it and the copper may be prevented. This jar being nearly filled with dilute sulphuric acid, the plates are immersed and the current of electricity evolved, directed by the conducting wires to any point the operator pleases. When the experiment is completed, the zinc plate should be lifted out, to prevent unnecessary waste, and again immersed when a fresh current is required.

323. If, instead of immersing the zinc and copper plates in dilute acid (321), they had been placed in water only, chemical action and evolution of electricity would have ensued, but with much less energy; the electricity being evolved in very small quantity, in consequence of the very low intensity of the chemical action of water on the zinc. In a solution of common salt, the effects are more obvious, the chloride of sodium being decomposed and chloride of zinc formed—the chlorine being the negative and sodium the positive elements (319); and electricity is evolved from the decomposition of the salt in the same manner as it was from that of the water (321).

324. The quantity of electricity evolved, increases with the surface exposed to the chemical action of the fluid in which it is immersed; and hence gigantic plates have been constructed for the purpose of obtaining an immense quantity of electricity. Mr. Pepys had an electromotor made for the London Institution, consisting of a copper and zinc plate, each fifty feet long and two wide, rolled into a coil, with horse-hair ropes between them to prevent their touching each other. About fifty gallons of dilute acid were required to act upon these plates, and the torrent of electricity evolved was truly immense.

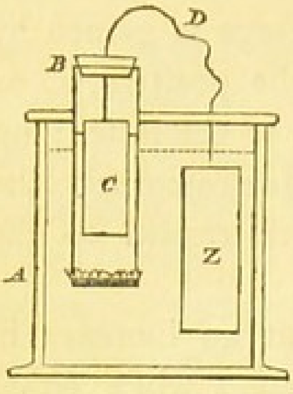
324.* Bearing in mind, that the evolution of electricity bears a direct relation to the amount of chemical action exerted on the most positive metal employed, and increases with the extent of surface acted on; we are capable of increasing the evolution of electricity to a considerable amount by a proper arrangement of apparatus. It is found from experiment that a considerable advantage is gained by causing the negative element to *surround* the positive, so as to present a surface opposed to both sides of the latter; on which account, in all well-constructed electromotors, the zinc element is placed in the centre with regard to the copper.

It has been, however, lately stated * that an increase in the quantity of the evolved electricity ensues when either the zinc or copper exceed each other in size, and that the quantity of excited electricity is at a minimum when the metals expose equal extent of surface. If the zinc plate be the largest, the maximum effect is said to be obtained when it is seven times larger than the copper; and if the latter be the largest plate, that the maximum evolution of electricity occurs when it is sixteen times larger than the zinc plate. In the former case the quantity of electricity is three, and in the latter four and a half, times greater than when the plates of copper and zinc are of equal size. Experiments are, however, wanting on this subject.

325. If the plates of zinc and copper, instead of being acted upon by a dilute acid, be immersed in a solution of sulphate of copper, chemical decomposition and consequent evolution of electricity will occur; the copper being deposited, in a metallic state, on the surface of the copper plate used. No gas is in this case evolved, as the sulphate of copper is alone decomposed; the sulphuric acid and oxygen acting on the zinc forming the sulphate of that metal, which is dissloved by the water. Thus the battery or eletcromotor (322), may be advantageously excited with a solution of sulphate of copper, instead of dilute acid.

326. In all these arrangements, both plates are immersed in the same exciting fluid; but considerable advantage is gained by employing two different fluids. This mode is

* Binks, in Phil. Mag. vol. ii. p. 68.



founded on facts long known, but first applied to the construction of electromotors by Professor Daniell.* The theoretical action of these arrangements is readily explicable: let A be a vessel filled with a solution of common salt (chloride of sodium); B a tube immersed therein, furnished at its lower part with a diaphragm formed of a piece of bladder, and filled with a solution of sulphate of copper; a plate of copper, C, connected with one of zinc, Z, by the wire D, are immersed in these fluids. The positive element Z decomposes the chloride of sodium, uniting with the negative chlorine, forming chloride of zinc, and repelling the positive sodium, which passes through the bladder diaphragm to reach the negative plate C; here it enters the solution of sulphate of copper, which it decomposes, uniting with the sulphuric acid and oxygen to form sulphate of soda, and setting free copper, containing free positive electricity, which is given up to the plate C, and passing along the wire D to Z, decomposition goes on as before (340). In this apparatus, after the current has continued passing for a sufficient time, we shall find the fluid in A converted partly into chloride of zinc, and that in B into sulphate of soda; whilst the beautiful crystals of copper deposited on C, will be found to bear that relation to the quantity of zinc dissolved to form the chloride, which the atomic weight of copper does to that of zinc. If the wire D were cut across in the middle, chemical decomposition and evolution of electricity would cease, until they were united by being placed in contact, or connected by means of a good conductor.

327. As in this apparatus (326), the inductive action of the two plates on each other is limited by the area of the base of the tube B, through which alone a current can pass

* Phil. Trans. 1836.

from one to the other through the fluid, the evolution of electricity will be increased by replacing the tube B by a bag or reservoir of animal membrane, as a bladder; and this constitutes the form of apparatus usually employed. A piece of sheet copper is rolled into a cylindric form, and placed in a bladder fastened round its upper part by a piece of string; the whole being placed in a jar, containing a concentric cylindric roll of sheet zinc; a metallic wire, or conductor, is soldered to each plate. A solution of sulphate of copper is poured into the bladder, and one of common salt, or sulphate of soda, is placed in the jar, exterior to the bladder, so as to act upon the zinc plate.

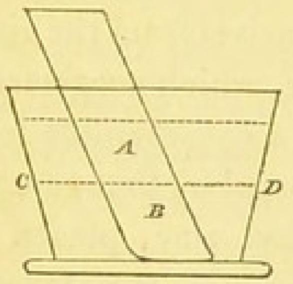
The inconvenience of this arrangement arises from the zinc being placed on the outside of the copper, which necessarily produces, as Professor Daniell has shown, a considerable loss of power;* accordingly, the arrangement used by that gentleman, consists of a cylinder of amalgamated zinc, placed in the centre of a hollow cylinder of copper; the former being surrounded by a piece of ox-gullet or bladder. The exciting fluid acting on the zinc, is dilute sulphuric acid, the copper cylinder being filled with a solution of sulphate of copper. On connecting the two plates, by means of a wire, the zinc plate decomposes the water (321), its hydrogen being positive, is repelled by the positive zinc, and passes through the membranous bag, towards the copper plate, where it is not evolved, but aids the decomposition of the sulphate of copper; uniting with the oxygen of the oxide to form water, and causing the copper to be deposited in beautiful crystals, on the surface of the copper element.

328. It is by no means necessary to use two different metals to obtain an electric current; for if but one be used whose surface is so constituted as to be unequally acted upon by the fluid in which it is immersed, electricity will be evolved; the portion of the metal most acted upon becoming

* Philosophical Transactions, 1838, p. 41, et seq.

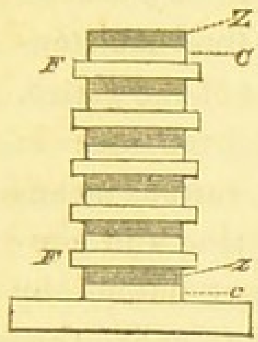
the positive element. Thus, a plate of rolled, and one of cast zinc, constitute an effective voltaic arrangement; as does also a plate of new clean zinc, with one which has been previously corroded by an acid. A new and a corroded plate of copper acted upon by nitric acid, also evolve electricity.

329. If but one metal of equal surface be used, no electricity will be evolved, unless acted upon by fluids exerting different chemical actions upon it. Thus, a plate of smooth iron acted on, on one side by dilute sulphuric acid, and on the other by water, sulphate of copper, &c. constitutes an effective arrangement. Let a plate of copper, AB, be placed in a glass vessel, and a saturated solution of sulphate of copper poured in up to the line CD, so that about one third of the plate may be immersed. On the surface of this fluid slowly pour some very dilute sulphuric acid, or weak salt and water; taking care that the fluids do not mix. Under these circumstances the upper part of the plate, A, will be slowly acted upon by the sulphuric acid; the lower end B becoming the negative element, decomposition of the sulphate of copper slowly takes place, and that metal becomes deposited in a crystalline form, on that part of the copper plate which is immersed in the sulphate of copper.



330. In all these various modes, we are enabled to cause the evolution of electricity in considerable quantities, but in a state of extremely low tension. To Volta, we are indebted for the discovery of a mode of increasing its tensile state, and by the contrivance of his magic pile, putting into the hands of philosophers an instrument of analysis and investigation, infinitely exceeding in its wonderful effects, any of the means of experimental research before discovered. Omitting the earlier experiments of Volta, or the mode of reasoning by which he was led to this discovery, as out of place in a work of this description, it will be sufficient to

observe that, by combining the action of several pairs of plate, (321), an infinite increase of tension and power is gained.



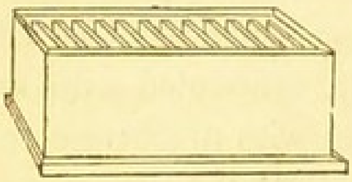
To understand the construction of the voltaic pile, place a plate of copper, C, on the table, and on this one of zinc, Z. A piece of thick flannel F, moistened with a dilute acid, brine, or even water, is placed on the zinc; a plate of copper on this, and so on; copper, zinc, wet flannel—copper, zinc, &c. until any number of alternations are used. Place the whole pile on an *insulating* stand, and connect the lower plate C with the condenser (298), connected with an electrometer; the gold leaves will diverge with negative electricity. Then connect the upper plate Z with the condenser, and the leaves will diverge with positive electricity. In an insulated pile of any number of alternations the electric tension of each kind of electricity is observed to increase from the centre to the extremities.

331. The source of the electricity in the pile is easily traced to chemical action; for in the lowest pair of plates in the last figure, the zinc is attacked by the fluid in the wet flannel, electric equilibrium is destroyed, the negative fluid escaping by the copper plate C to the earth, the positive being retained in the zinc. In the second couple, the negative electricity expelled by the chemical action on the second zinc plate, passes to the first zinc, and restores its electric equilibrium by combining with the positive fluid *adhering* to it; and these series of actions are repeated to the top of the pile. No greater *quantity of electricity being obtained from a pile, than from a single pair of plates;* its tension alone being increased*, as the chemical action and disturbance of electric equilibrium, in the intermediate plates of the pile or battery, are exerted only in urging on the currents to the terminal

* Faraday, Phil. Trans. 1834. Exp. Researches, Series 8th, par. 991.

plates, thus increasing, as it were, the momentum and consequent tension of the electricity evolved.

332. The power of the pile decreases, and finally ceases, with the neutralization and evaporation of the fluid moistening the pieces of flannel, and with the oxydation of the plates. These constitute sources of considerable inconvenience in experimental investigations; to diminish which, various means have been proposed, as by fixing the pairs of zinc and copper in a trough of wood, and replacing the wet flannel by



fluids poured into the cells thus formed; constituting Cruikshank's arrangement. This is very convenient, especially when a solution of sulphate of copper is used for the exciting fluid; which, as Dr. Fyfe has shown, increases the electro-chemical intensity of the electric current as compared with that evolved by dilute sulphuric acid, in the proportion of seventy-two to sixteen.

A great improvement in the construction of these batteries was effected by Dr. Wollaston, who fixed the zinc and copper plates to a wooden beam, and immersed them when required for use in an earthenware trough, furnished with partitions of the same substance, and filled with the exciting fluid. This arrangement is rendered still more effective by causing each zinc plate to be completely surrounded by the copper plate of the next pair.

Dr. Faraday has proposed an excellent arrangement,* in which the metals are brought as close to each other as possible, the alternate zinc and copper plates being separated, not by partitions of earthenware, but by pieces of stout cartridge paper or card.

333. A series of pairs constructed on Professor Daniell's principle (326), affords a most valuable source of electricity

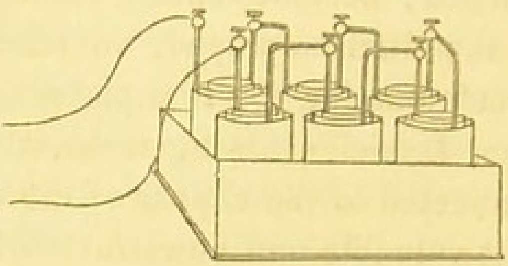
* Phil. Trans. 1835, 10th Series, Exp. Researches, 1123.

of tension, and has, moreover, the advantage of being constant in its action for several hours, whereas, the others above mentioned, although very energetic on the first immersion of the plates; become rapidly weakened by the continual action of the fluid employed, an effect but partially prevented by amalgamating the zinc plates (321). A dozen pairs on Professor Daniell's arrangement, the zinc cylinder of one being connected to the copper of the next, and so on, constitute a most valuable and powerful voltaic battery. A very efficient arrangement is made by connecting in a similar manner, a dozen pairs of zinc and copper cylinders, separated by means of bladder diaphragms, the zinc being acted on by common salt, and the copper by sulphate of copper; this has the advantage of cheapness, and of being readily constructed. The zinc and copper plates are most conveniently connected by copper wires, fixed by a binding screw soldered to each plate.

334. As bladders and other membranous diaphragms have the disadvantage of becoming rapidly corroded, and pierced, by the action of the exciting fluids, and of becoming torn by the sharp edges of the crystals of metallic copper deposited on the copper plate; various attempts have been made to substitute for them cylindric vessels of porous earth. Vessels of this kind, like wine-coolers, have been used by Professor Daniell and myself; but, on account of their thickness, so much obstruction is offered to the transit of the electric current, that their use became extremely limited. Lately some very excellent porous jars, composed of the thinnest unglazed white biscuit-ware, have been introduced, and are so extremely convenient that I always use them, in preference to bladders.* A battery constructed in this manner is figured

* These porous jars were first, I believe, used for this purpose by Mr. Dancer, a philosophical instrument maker of Liverpool; at least, I am indebted to him for the knowledge of their utility, and for the supply of those which I now use.

below, each zinc plate being furnished with a stout copper wire bent at right angles, and connected with the copper plate of the next pair by means of a binding screw fixed to it.



The copper plates are readily raised from the porous earthen jars and cleaned, a very necessary process, but one which is very inconvenient when bladders are employed. Cylindrical vessels of thin wood, or thick brown-paper, are occasionally employed instead of bladders or earthenware diaphragms. A thick wire of copper, ZC, is screwed on the terminal zinc and copper plates of the battery for the purpose of conducting the electricity to any substance submitted to its action.

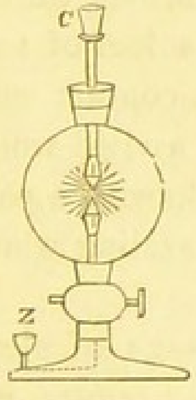
335. If a pile or battery, be constructed like the one originally contrived by Volta (330), providing there are at least thirty alternations, and any person touching the top and bottom of it at the same instant with his moistened hands, the electricity accumulated at each end of the pile will discharge itself through his arms, producing an *electric shock.* If a piece of well-burnt charcoal be placed upon the uppermost plate of the pile, and a wire communicating with the lowest be brought in contact with it, a series of faint sparks will become visible on drawing it over its surface.

336. Let the wires connected with the terminal plates of a battery (which, if consisting of plates excited by a dilute acid (332), should consist of at least forty pairs, each being four inches square; or if of the construction of Professor Daniell's arrangement, or any of its modifications (334), should consist at least of ten pairs, the copper plates presenting a surface of about one hundred square inches,) be connected to the two moveable rods A B of the universal discharger (292), and having unscrewed the knobs, tie on each rod by means of thin

copper wire, a pencil of well-burnt boxwood charcoal, or still better, of that plumbago-like substance found lining the interior of long-used coal-gas retorts. On moving the rods of the discharger, so that the pieces of charcoal may lightly touch each other, a vivid light will appear between them, igniting their extremities and heating the air so intensely that on allowing the charcoal points to be drawn a little distance from each other, the discharge will continue with a most dazzling light through the intermediate portions of heated air.

If the apparatus be very small, as with a single trough on Wollaston's construction, of ten pairs of plates, a piece of the charcoal should be fixed to one of the terminal wires, and the other having a piece of platina wire fixed to its end should be brought in contact with the carbon; at the point of contact a vivid dazzling light will be evolved, the platina wire will be ignited, and, if thin, melted into globules.

337. This evolution of light does not depend upon the combination of charcoal terminating the conducting wires, for it will take place with still greater splendour in an air-pump vacuum. This may be shown by allowing the wire holding one of the pieces of charcoal, to slide air-tight through the brass neck of a glass globe; a second piece being fixed to a wire, fastened to the lower part, and connected with a brass cup, z. On exhausting the globe of air, connecting the terminal wires of the battery with the brass cups cc, and approximating the charcoal points sufficiently, an evolution of intense and dazzling light will ensue.



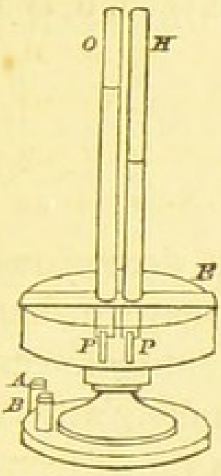
These experiments are of the most brilliant kind of any in experimental science, especially when performed by the aid of a large battery, as that belonging to the Royal Institution, consisting of 2000 pairs of plates, presenting an active surface of 128,000 square inches. In this case a very curious transfer of carbon from the positive to the negative electrode (341) is observed, the piece of charcoal constituting the former presenting a conical cavity from this loss of substance.

338. If the terminal wires of a voltaic battery be connected by means of a fine platina wire, if the battery be sufficiently large, it becomes heated to redness, and even melted. A small battery will heat a considerable quantity of wire, a single pair of small plates, igniting an inch or two; and a battery consisting of ten alternations (336), will heat to redness about eight inches. The best mode of showing this, is to roll about eighteen inches of wire into a long spiral, and place it in the interior of a glass tube; its end passing through corks, so as to be readily twisted round the terminal wires of a battery. If this be too small to ignite the wire, it will heat it sufficiently to communicate a very high temperature to the glass tube in which it is placed; so that phosphorus may be inflamed by bringing it in contact with its exterior. By immersing this tube in a small quantity of water, the latter may be speedily raised to the boiling point. If thin metallic leaves be subjected to the action of the current of the battery, they inflame and burn with considerable brilliancy. This experiment is best performed by fixing a plate of polished tinned iron to one wire of the battery, and taking up a leaf of any metal, on the point of the other wire, bring it in contact with the tin plate. In this manner, gold burns with a vivid white light, silver with an emerald green, copper and tin with a pale bluish, lead with a purple, and zinc with a dazzling white flame.

339. Under certain circumstances, the passage of electricity through metallic conductors will actually *reduce*, instead of elevating their temperature. Thus, if two bars of bismuth and antimony be soldered across each other at right angles, and they be touched with the conducting wires of the battery, so that the positive electricity will have to pass from the antimony to the bismuth, the temperature of the metals will be elevated; but when the current moves in the opposite direction, viz., from the bismuth to the antimony,

the metals become cooled at their point of contact. If a cavity be excavated at this point, and a drop of water previously cooled nearly to 32° be placed therein, on the current passing, the water will become rapidly frozen.*

340. Let the terminal wires of a battery, consisting, at least, of eight or ten pairs of plates, in good action, be placed in the cups AB, containing a few drops of mercury, and communicating with the platina plates PP. The tubes OH are filled with water rendered conducting by the addition of sulphuric acid, and inverted in the vessel E, filled with the same fluid, over the platina plates PP. Directly connexion is made with the battery, the platina plates will become covered with bubbles of gas, which being evolved, will rise in the tubes OH, in unequal proportion, rather more than *twice* as much gas being collected in a given time, in one tube than in the other. This gas consists of oxygen and hydrogen, the former being evolved at the surface of the platina plate, where the current of positive electricity enters the fluid in E, and the hydrogen at that surface where it leaves the fluid. As these gases are evolved from the decomposed water, their volumes ought to be to each other as two to one; the reason why they are not precisely in this proportion, is to be found in the partial solubility of oxygen in water; and hence, its real volume is rather less than it would be, if this source of fallacy were absent. In this experiment, the gases are evolved from both plates simultaneously; and, although at each instant, but a single atom of water is decomposed, the hydrogen being evolved from one, and its oxygen from the other plate, the gases are not observed to pass from P to P, the



* E. Lenz, Einige Versuche im Gebiete des Galvanismus. Pog. Annal. xliv. p. 342.

fluid between these electrodes (341) being free from bubbles. This circumstance may be thus explained: let the two platina plates be represented by the letters PN, the former being that at which positive electricity is supposed to enter, and N that at which it leaves the acidulated water; ABCD, are supposed to be four atoms of water lying between the plates, PN, each consisting of an atom of oxygen, O, and one of hydrogen, H.

A B C D

P........ OH, OH, OH, OH,........N.

The positive electricity entering the fluid at P, decomposes the atom of water A, causing the evolution of oxygen, and repelling its hydrogen; this being carried forward by the influence of the current, decomposes the atom B, uniting with its oxygen, and repelling its hydrogen, which, in its turn, decomposes the atom C, and so on; at last, the hydrogen of the atom D is set free, and is evolved at the surface of the plate N, as the positive electricity, by whose influence the decomposition of the atoms ABCD was effected, leaves the fluid at this point. A similar explanation is applicable to other cases, in which electrolytes (345) being decomposed, the elements are evolved at distant portions of the fluid traversed by the current (321,323,326, &c.)

341. The terminations of the conducting wires of the battery, which, in the above experiment are the plates PP, constitute the points, or doors, at which the electric currents from the battery may be supposed to enter the fluid; and hence, have been aptly termed by Faraday, *electrodes*,* that, at which the positive electricity enters the fluid is termed the *positive*, and the other, or that by which the negative enters, is termed the *negative* electrode. The term poles, was formerly applied to these electrodes, under the supposition that they decomposed fluids by their attracting the

* Ἤλεχτρον and ὁδὸς, via.

separated elements towards them, an idea now proved to be incorrect.*

342. The positive electrode, whether of a single pair, or of a series, constituting the voltaic battery; is always that wire which is connected to the last *active* copper plate, and the negative that connected to the last *active* zinc. Much unnecessary confusion, with regard to the expression of the negative or positive side of the battery has been introduced in many works, from the want of a rule like that given by Faraday, of connecting their sides with a given direction of of the current (341). Thus, in a battery constructed according to Cruikshank's arrangement (332), the positive electrode, or *pole*, is that wire which is connected to the last zinc, and the negative to the last copper-plate. This difference is only apparent, and all obscurity will vanish by referring to the original voltaic pile (330), when the wire from the last zinc is the positive electrode, for this reason, that the last zinc is in metallic connexion with the copper-plate next to it; and hence, merely acts as a conductor from it, without adding to the power of the pile. Remove the terminal plates, and then all obscurity will vanish, for the positive electrode will be in actual contact with the last copper-plate, as the intervening and *masking* plate is removed. In a Cruikshank trough, excited by an acid or saline solution, the positive electrode will be that which is fixed to the end, towards which, *all the zinc plates look*; and the negative, that fixed to the end towards which *all the copper-plates look.*

343. If, instead of platina electrodes, the copper wires themselves be plunged in the dilute sulphuric acid (340), water is, as before, decomposed, hydrogen being evolved at the negative electrode; whilst at the positive, the oxygen combines with the metal of which the wire is composed, forming an oxide which dissolves in the acid present.

* Faraday, Philosoph. Trans. 1834, 7th Series, 661 et seq.

344. If several pieces of apparatus for the decomposition of water (340) be arranged, so that the current of a battery may pass through each in succession, the quantity of gases evolved in each will be found to be precisely equal. And, if the current, besides passing through one of these pieces of apparatus, is made to traverse a metallic solution, as sulphate of copper; the quantity of copper precipitate in a metallic state, will bear the same relation to the quantity of oxygen and hydrogen collected, as their atomic weights do. Thus, a current of electricity capable of decomposing 9·01 grains of water will decompose 58·78 of chloride of sodium, 163·28 of acetate of lead, 79·88 sulphate of copper, &c. This arises from the *definite nature of electro-chemical, or electrolytic decomposition*, a fact first demonstrated by Dr. Faraday.*

345. Compound bodies, capable of being decomposed by the agency of electric currents, are conveniently termed *electrolytes*.† Before an *electrolyte* can be decomposed, it is necessary that it should be capable of allowing induction (248), and consequent conduction to take place through it; as the latter cannot occur in the great majority of cases, whilst the electrolyte is in a solid state, it must be dissolved in water, or fused, in which state it generally readily conducts the current. Thus, the chlorides of tin, silver, and lead, are readily decomposed‡ when the current is transmitted through them, whilst they are in a state of fusion (301).

346. Before the current can traverse a fluid, induction and polarization of the particles of the latter, like the molecules of a dialectric in the act of charging (279) must take place. This may, to a certain extent, be proved, by placing some filaments of dry silk in oil of turpentine, and

* Phil. Trans. 1834, 7th Series, section 7.

† ἤλεκτρον, and λυο, solvo.

‡ The act of electio-chemical decomposition is termed electro-lysis.

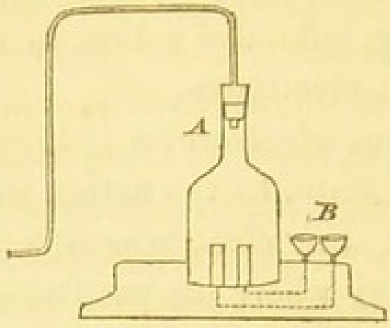
plunging the electrodes of the battery in the fluid, the silk will be arranged by inductive action in a tolerably regular line between the two electrodes.

347. When various *electrolytes* (345) are submitted in a dissolved, or fused state, to the action of the current from the voltaic battery, the *electro-negative* elements are set free at the electrodes where the positive current is supposed to enter the fluid; and the *positive* elements, where it leaves it. Thus, if chloride of sodium, iodide of potassium, hydrochloric acid, sulphate of copper, nitrate of lead, or fused chloride of lead, be submitted to the action of the current, the chlorine, iodine, sulphuric, and nitric acids will be set free at that point where the positive current enters the solutions or fused mass; whilst at the electrode where it leaves them, the soda, potassa, hydrogen, copper, and lead, will be developed in an isolated state.

348. In experiments on voltaic electricity, it is necessary to make a distinction between the *quantity* and *intensity* of the electric current; the former bearing, *cæteris paribus*, a relation to the size of the plates, and the latter to the number of alterations. A pile, or other voltaic arrangement of fifty pairs excited by pump water only, will readily cause the gold leaves of the electrometer to diverge, and will produce a sensible shock; but will scarcely decompose even a small portion of water in a space of time sufficient, when the battery is excited by an acid, to rapidly resolve the same quantity into its gaseous elements.

349. As the only true test of the intensity of a voltaic current is its *electrolytic* power, the volta-electrometer, as it is termed by Dr. Faraday,* becomes a valuable instrument in giving an approximative measure of the power of a battery, or pile. This consists of any apparatus, in which water is

* Phil. Trans. 1834, 701-741.



submitted to the action of the current, so that the gases into which it is resolved may be measured. The most convenient form of this instrument consistss of a glass vessel, A, fixed into a wooden base, having two plates of platina passing into its interior, connected by wires with cups or binding screws, B. The glass vessel being filled with dilute sulphuric acid, has a bent glass tube passing through a cork fixed into its mouth, so as to convey the gases evolved into a graduated receiver, standing in a pneumatic trough. The platina electrodes employed in this apparatus to effect the decomposition of water, assume peculiar properties, by which, on being disconnected with the battery, they develope a secondary current passing in a direction opposed to that of the battery current. This may be detected by connecting the cups B of a volta-electrometer with a delicate multiplier (362), after removing the battery wire, the needles will immediately traverse, from the action of this secondary current. The electrodes do not lose this property entirely, by pouring out the acidulated water in which they are immersed, and replacing it by fresh, or even by washing them with hot water. If a rod of amalgamated zinc be plunged into the acidulated water contained in a volta-electrometer, whose platina-plates have been previously connected with a voltaic battery for a few minutes, and wires twisted round its upper end be connected with the two cups B, decomposition of water will, of course, ensue (321) and hydrogen will be evolved from both platina plates but in unequal volumes, nearly twice as much being evolved from one as from the other, as I have elsewhere shown.* This curious polarised condition of the electrodes, in all probability arises from the *fixation* of small portions of oxygen and hydrogen on their surface, a view countenanced by the experiments of Schönbein,† who has found similar properties to be assumed by platina plates after immersion in oxygen, chlorine, bromine-vapor, &c.

350. It is necessary, for the whole electrolytic force of a voltaic current to be effectually excited, that all parts of the circuit should be formed of as good conductors as possible, as the amount of decomposition is in a ratio to the facility with which the current passes. Hence, a fluid not readily acted upon by the current in its pure state, often readily yields to its influence, when made to conduct it more readily: thus, pure water conducts badly, and is decomposed with extreme slowness; on the addition of sulphuric acid it becomes an excellent conductor, and is decomposed with facility (340).

351. Although compound batteries have been referred to in the above remarks, as necessary to produce chemical decomposition, yet it must not be supposed that they alone are efficacious; for a single pair of plates properly constructed, is capable of effecting, by the current evolved, most important decomposing actions in bodies whose elements are held together with the greatest force. Dr. Faraday decomposed iodide of potassium (a salt capable of very ready decomposition by a small force,) alkaline chlorides, and sulphates, hydrochloric acid, and even water, by the aid of a single pair of plates. M. Becquerel,‡ by availing himself of weak currents, aided by "affinities well chosen," succeeded in decomposing

* Phil. Magazine, 1839.

† Poggendorff. Annalen. xlvii, p. 104.

‡ Traité de l'Electricité et du Magnétisme, vol. iii. p. 228, et seq. Paris, 1835.

the salts of aluminum, magnesium, zirconium, and silicon acid; and obtaining their metallic bases in the form of crystalline alloys. Subsequently, I succeeded,* by using *a constant current of low tension*, in decomposing fluorides of silicon, and the chloride of potassium, sodium, and ammonium; and in obtaining the metallic base of the former in a pure state, and those of the three latter salts as amalgams. The amalgam of ammonium being so light, that it floated in water, in which, of course, it rapidly underwent oxydation.

352. Decomposition of several electrolytes, as sulphate of soda, iodide of potassium, &c. may be effected by means of a current of electricity, from the ordinary electrical machine (260). For this purpose, place upon the table of the universal discharger (292) a piece of bibulous paper, soaked in a solution of some saline combination, as iodide of potassium; fix to each of the sliding rods of the apparatus a piece of fine platina wire, to serve as electrodes, these are to rest lightly upon the paper, about an inch from each other. Connect one of the rods with the rubber of the machine, or with the earth, by means of a chain, and the other with the prime conductor by a wire, or still better, by a piece of wet string (293, D); on working the machine, the salt will be decomposed. Iodine being set free at that wire which is connected with the conductor, and the alkaline base at that which is connected with the rubber. The latter element can be detected by placing a piece of turmeric paper, moistened with the solution employed, on the table of the discharger, in place of the ordinary bibulous paper. Here, as in voltaic decomposition, the negative element is evolved where positive electricity enters the fluid submitted to its action (347).

353. Electricity is not only evolved during chemical decomposition, but during *chemical combination;* a fact first

* Observations on the electro-chemical influence of long-continued electric currrents of low tension. Philosophical Transactions, 1837, page 37.

announced by Becquerel. The truth of this statement has been, by many, either altogether denied, or limited to the case of the combination of nitric acid with alkalies. But after repeating the experiments of Becquerel,* as well as those of Pfaff, Mohr, Dulk and Jacobi,† I am convinced that an electric current, certainly of extremely low tension, is really evolved during the combination of sulphuric, hydrochloric, nitric, phosphoric, and acetic acids, with the fixed alkalies, and even with ammonia. This is a question, however, which it is not appropriate to canvass in a strictly elementary work, notwithstanding its great importance in relation to chemical philosophy.

354. A curious modification of the voltaic battery is found in those arrangements termed *dry piles:* these consist of a large number of alternations of some metal in a state of extreme tenuity, as silver, combined with one more oxydizable, as tin, and alternated with pieces of writing paper. The moisture in the latter substance appears to act as the exciting fluid on the most oxydizable metal. Thus, a pile composed of pieces of tin-foil and silvered paper, if containing about 200 alternations, will act powerfully on the gold-leaf electrometer by aid of the condenser (298). The piles of Zamboni are the most convenient: these are constructed by pasting on one side of a sheet of paper, finely laminated zinc, and covering the other side with finely-powdered black oxide of manganese. On cutting discs out of this prepared paper, and piling them upon each other, to the number of 1000, taking care to press them together, a little pile will be obtained capable of diverging the gold-leaves of the electrometer to the extent of half an inch, on touching its cap with one end of the apparatus, the other being connected with the earth.

These dry piles continue in action during several years,

* Traité de l'Electricité, v. p. 215; and Compts rendus de l'Académie, vi. p. 125.

† The papers of these philosophers are in Poggendorff's Annalen. xl. pp. 67, 443; xlii. pp. 76, 91; and xliv. p. 542.

and are capable of yielding a spark by means of the condenser, although not the faintest shock, nor the slightest evidence of chemical action has yet been obtained from them. The electricity they yield appears to be of high tension, but extremely minute in quantity, and disappears altogether when the paper discs have lost all their humidity by spontaneous evaporation.

NOTE.

To the no less excellent than laborious Traité de l'Electricité et du Magnétisme, of Becquerel, I beg to refer the student for an elaborate account of all that is valuable in electrical science; especially, in that interesting part of the science connected with the application of electricity to chemistry, contained, chiefly, in the third volume. For an abstract of this in an English dress, I would also refer to the excellent Scientific Memoirs of Mr. Richard Taylor, pp. 414-42. The papers of Dr. Faraday, in the Philosophical Transactions, now fortunately collected into a separate work, cannot be too frequently or too attentively perused by those who wish to acquire a thorough acquaintance with this beautiful science. Nor ought the writings of Pouillet, Coulomb, Poisson, De la Rive, and many other continental philosophers, as well as those of our talented countryman, Prof. Daniell, to be overlooked by the student.

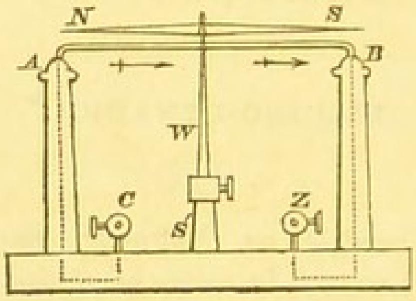
CHAPTER XVI.

ELECTRO-DYNAMICS.*

355. The direct influence of the discharge of electricity of tension, on magnetic needles, was studied long ago by Franklin, Beccaria, Wilson, Cavallo, and others; the power it exerted of destroying, reversing, or communicating polarity was also pointed out. But it was reserved for Prof. Oersted, of Copenhagen, to announce to the world the existence of a new and peculiar force reciprocally exerted between magnetic bars, and the connecting wires of a voltaic battery (341); a fact, to a certain extent, theoretically anticipated in a work, by the same philosopher, published twenty years before his great discovery, which was made in 1820.

* ἤλεκτρον, and δύναμις, vis.

356. Let a copper wire, connected with the two sides of a voltaic arrangement (322), be stretched parallel to a magnetic needle, supported on a pivot, and on a plane just above it. The magnet will instantly leave its position in the magnetic meridian (215), and after a few oscillations will assume, and retain, a position at, or approaching to, right angles to the wire, as long as the current continues to pass. To show this, let a



thick brass wire be supported by two pillars AB, passing through their long axes, and soldered to the binding screws CZ. The magnetic needle NS is supported by a pointed wire W, fixed in a hollow stem S, in which it may be placed at any height by means of a screw. N is the austral and S the boreal pole of the needle (214): the former being what is commonly termed the north, and the latter the south pole.

(A.) Screw the wire coming from the copper plate of an electromotor (322) into C, and that from the zinc into Z, the positive current will pass in the direction AB, as shown by the arrows; and the needle NS, previously in the magnetic meridian (215), will move from its previous position, its end N, moving towards the *west*.

(B.) Depress the wire W into the socket S, so that the needle NS may be *beneath* the conducting wire. On making connexion with the electromotor as before, the end N of the needle moves towards the *east*.

(C.) Remove the wire W, and the magnetic needle, replacing it with one arranged as a dipping needle (216), parallel to, and on the same horizontal plane with the conducting wire AB. On making connexion with the electromotor (A), the end N of the needle will be *elevated*, providing its poles be in the same position as before, and it be placed on the *west* side of the wire AB.

(D.) Arrange the apparatus as before (C), but let the dipping needle be placed on the *east* side of AB; its poles retaining their former direction. The pole N will then be depressed.

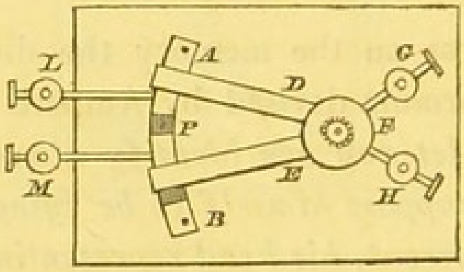
357. If these experiments be repeated, the connexion with the electromotor (322) being reversed, so that its copper plate may be connected with the screw Z, and its zinc with the screw C, the direction of the magnetic deviations will also be reversed.

358. To impress on the memory the directions of these deviations, the formula devised by Ampere is extremely useful: to use this, *let any one identify himself with the current, or let him suppose himself to be lying in the direction of the positive current, his head representing the copper and his feet the zinc plate, and looking at the needle, its north pole will always move towards the right hand.* This will be readily apparent if the student will suppose himself to be lying on the wire AB (356), in the direction of the positive current and looking towards NS, and then repeat the above experiments (356-7).

359. The amount of action exerted on the magnetic needle by the electric current, appears from the researches of Biot and Savart * to diminish with their mutual distance, its intensity being in the inverse ratio of the square of the distance of the needle from the wire, *when considered as applying to a small section of the conducting wire*; and of course proportional to the sine of the angle of deviation. But as the length of the current may be considered to be infinite with regard to the needle, its intensity is in the inverse ratio of the simple distance, when considered as being exerted by an indefinitely long conducting wire.

* Précis de Physique, par M. Biot, tom. ii. p. 707. Paris, 1824.

360. To avoid the trouble and difficulty of reversing the direction of the battery current in electro-magnetic experiments, several pieces of apparatus have been contrived, most of which are very inconvenient, from their requiring mercury to fit them for use. I have had an instrument constructed, which when used to connect the battery with any apparatus, allows the direction of the current to be readily charged without using that fluid metal. This consists of an elevated curved ridge, consisting of three stout pieces of brass APB, separated in the figure at the dark portions by wood: A and B com-



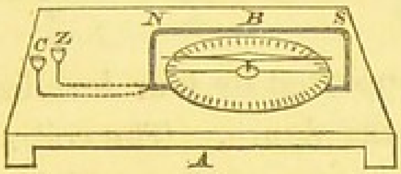
municate by means of a thick wire passing under the base of the instrument. Two thick quadrangular bars of brass, DE, pass through a circular piece of wood, F, and terminate in the binding screws GH. The bars DE, and the piece F moving with it as on a centre, being made to press upon the curved ridge AB by means of a screw at F. Two other binding screws, LM, are connected to A or B, and to P. If the bars be placed as in the figure, the copper plate of a battery being connected to G, and the zinc to H, the positive current will flow from L to M if they be connected by means of a wire or any piece of apparatus. Let the bars be then moved until the end of E rests on B, D will of course be on P, and instantly the positive current will move in the opposite direction, or from M to L.

When this instrument, which I propose to call the *inversor*, is used, a drop of oil should be placed on APB, to allow DE to glide readily over them.

361. From a consideration of the above experiments, it is obvious that if a conducting wire be bent into the shape of a

rectangle, the needle being placed between its two horizontal branches, the action of a current traversing the wire will be, to move the needle in the *same* direction; for although one branch is above, and the other below the needle, yet as the current moves in each in opposite directions, its effects on the magnet will be the same in each.

In this manner we possess a mode of increasing the action of a current on the needle to an extraordinary degree, and acquiring a mode of detecting traces of electricity infinitely too minute to act on the gold-leaf electrometer. For these valuable contrivances we are indebted to the ingenuity of Schweigger. The commonest form of these instruments, galvanometers or multipliers, as they are termed, consists of a rectangular coil of copper wire NBS, containing about twenty

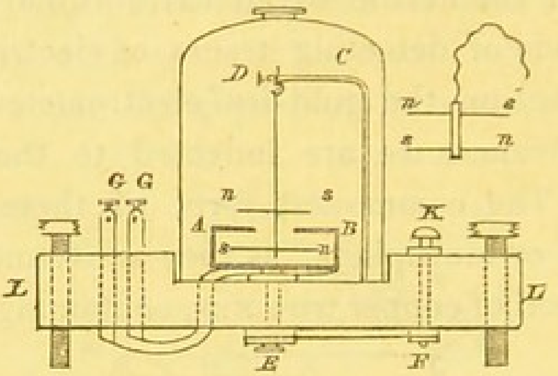


convolutions, the wire being covered with cotton or silk, to prevent the lateral escape of the current. The cups CZ are connected, respectively, to an end of the wire coil, NBS. A magnetic needle, supported on a pivot, is placed in the centre of the coil, and a card, graduated into 360°, is fixed to the board A on which the coil rests, so that a line drawn from 360° to 180° coincides with its long axis. On connecting any source of feeble electricity to the cups CZ, the current will traverse the coil, and the needle will move to the east or west, according to the direction of the electricity.

362 This form of multiplier will, it is obvious, detect the existence of a current only when it is sufficiently intense to overcome the directive action of the earth (220), which tends to retain the needle in the magnetic meridian (215). If the current be too feeble to produce this effect, its existence cannot be detected without using a much more delicate instrument. To the late Chevalier Nobili, we are indebted for the application of the astalic needle to the multiplier, thus

enabling us to detect the existence of currents of the lowest tension, by annulling the directive (220) action of the earth on the needle. The following is a description of one of the many forms of multipliers that have been proposed, and which I prefer on account of its extreme sensibility, and the facility with which it is used :—

It consists of a firm base of mahogany, LL, excavated in



the centre, and supported by four levelling screws, of which two are shown in the figure. The coil AB is formed of copper wire one sixtieth of an inch in thickness, and about two hundred feet in length, carefully covered with cotton to prevent lateral contact. This wire is wound on a thin wooden frame two inches *square*, the upper and lower portions of which are about one inch apart, this frame is fixed to a circular piece of wood passing through the board LL, and ending in the grooved wheel E, connected by means of a piece of cord with the pulley F, moved by the handle K, so that when the latter is turned, the frame and coil AB are moved round their vertical axes. The ends of the coil, after being twisted into a loose spiral, pass through the board, and are soldered to the binding screws GG. The magnetic needles are thin, light sewing needles, about one inch and a half in length, possessing very nearly the same degree of magnetic intensity, and fixed about three quarters of an inch apart, on a piece of straw or card, as shown in the small figure, with their poles opposed in direction. The piece of straw is placed in the vertical axis of the coil, so that the lower needle may be between, and the upper one above the convolutions of wire ; the whole system being supported by means of a filament of unspun silk, or fine human hair, from the arm C, being readily raised or depressed by means of the screw D. A circular piece of card graduated into 360°, is placed on AB, and before the instrument is used, the folds of wire on the frame should be placed exactly parallel to the needles by moving K. A glass shade is placed over the apparatus to prevent any disturbance ensuing from currents of air. If any source of an electric current be connected to the screws GG, the needles will immediately deviate from their previous position, the intensity of the current being, in general, as the sine of the angle of deviation, especially as the needles used always possess some slight directive power (220). To illustrate the delicacy of this instrument, place on the top of one of the brass screws GG, a drop of spring water, and having a piece of zinc connected to the other screw, immerse its extremity in the drop of water, the needles will immediately be moved by the weak current thus set in motion. This multiplier constitutes one of the most valuable instruments in electro-chemical researches* that we are acquainted with.

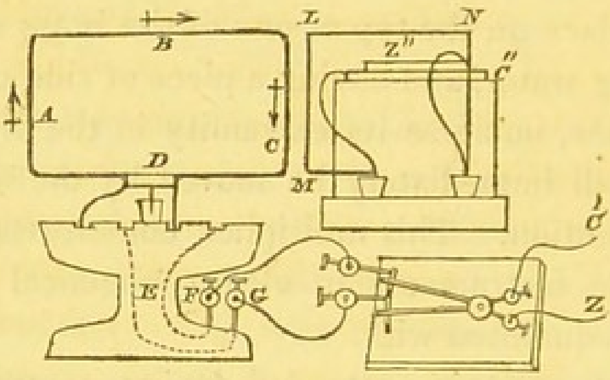
363. As all action is attended by its corresponding reaction (55), if in any of the experiments described, the magnets be fixed, and the conducting wires moveable, thus reversing the conditions of the experiment; the wires will be acted upon by the magnets, and assume a constant position with regard to the direction of the current, and position of the magnetic poles.

364. Let a thick curved wire be connected to an electromotor (322) so that the current may traverse it; divide it in the middle, leaving about an inch between the divided portions, and reconnect them by means of a piece of fine copper

* See a paper by Prof. Schönbein in Pog. Annalen, xlv. p. 263; entitled "Uber die Ursache der Farbenveranderungen, welche manche Körper unter dem Einfluss der Wärme erleiden," in which, by aid of this instrument, the author proves change in composition of the salt to occur, when a solution of chloride of cobalt turns blue by exposure to heat.

wire. On dipping this thin wire, whilst the current is passing through it, into iron filings, they will be attracted and adhere to it as if it had suddenly acquired magnetic properties. The filings will be attached to the wire in the form of rings, about one-twentieth of an inch apart, and will drop off the instant the current ceases to pass.

365. Wires conducting electric currents, *if free to move, attract each other when the currents are moving in the same, and repel each other when moving in the reverse direction.* To show this, let a frame, ABC, of copper wire be fixed to a piece of light wood, moving on a pivot, the ends of the wire dipping into two concentric cells, filled with mercury, and

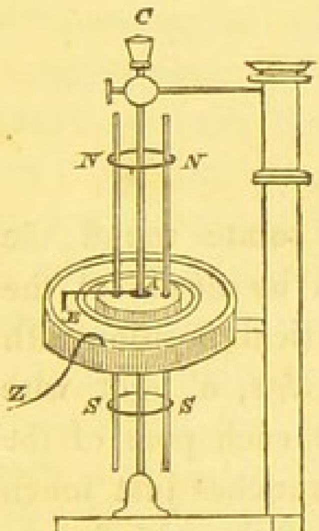


connected by wires passing through the stem E to the screws FG. These screws are connected by wires to the *inversor* (360), which by the wires C'Z is itself communicated to the two plates of an electromotor (322). A current thus traverses frame ABC, in a direction varying with the position of the bars of the inversor; let us suppose that the current of positive electricity moves in the direction shown by the arrows.

Place a thick curved wire, L N, in communication by means of cups of mercury, with the two plates Z'' C'', of a small electromotor. Approach this wire towards C; the positive currents will be descending both in C and in LM, and thus moving in the *same* direction, the frame of ABC will move on its centre to meet LM, mutual *attraction* ensuing. Then move the bars of the *inversor*, so that the positive current will ascend in C, instead of descending, and immediate *repulsion* will ensue.

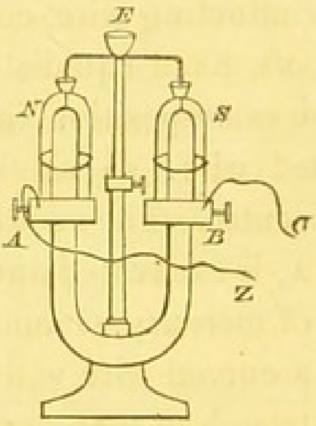
366. The action exerted by a conducting wire on a magnet (356), is obviously not a direct attractive or repulsive one; but is rather a tangential force, by which the opposite poles of the magnet tend to rotate round the conducting wire in different directions, and assume a state of equilibrium when the opposing actions of the wire on both poles become equally balanced. Reasoning on this fact, Faraday concluded, that if the action of the current could be confined to one pole only of the needle, perpetual rotation, providing no opposing forces interfered, might be produced. After a series of experiments on this subject, he succeeded perfectly, and thus developed one of the most interesting and extraordinary phenomena in electrical science.

The most convenient apparatus for illustrating this rotation of magnets round a conducting wire, consists of two or three slender magnets, NS, NS, fixed equidistant from each other, with their poles in the same position, in the piece of wood A, supported by a pointed wire, so as to move readily on its centre. The middle of the piece of wood A, is excavated and contains a few drops of mercury, communicating by means of a curved wire with the external circular trough of mercury E. A pointed copper wire, supported by a screw at C, dips into the mercury in A; and is furnished with a cup containing mercury, so as to be readily connected with an electromotor, by means of the *inversor* (360). The cup C and trough E are then connected, the former with the copper, the latter with the zinc plate of the electromotor. So that the positive current *descends* to A, and then reaching E through the curved wire, escapes to Z. It thus acts only on the poles NN of the magnets, which if austral poles (214), will immediately begin to rotate round the



conducting wire cc, from left to right, or in a direction like that of the hands of a watch. By turning the bars of the *inversor*, or otherwise changing the direction of the current, the direction of the rotation will immediately become altered. The same thing also occurs, when the position of the poles of the magnets are reversed. Let the magnets or currents be arranged as they may, the direction of the rotation always corresponds to the formula of Ampere (358). It may here be remarked, that in this as in all other experiments in electro-magnetism where wires dip into mercury, their ends should be cleaned and *amalgamated*, by being dipped into a solution of nitrate of mercury, to ensure perfect contact.

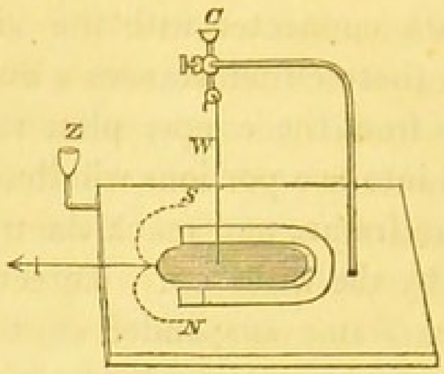
367. In accordance with the law of equality of action and reaction (45), if the magnets be fixed and the conducting



wires moveable, the latter will readily rotate round the former. This may be very easily shown by means of the horse-shoe magnets N S, placed in a vertical position with circular troughs, AB, screwed upon its legs, a light wire frame supported by a fine steel point on each pole of the magnet, is so arranged that its vertical branches just touch the surface of the mercury in A B. Each of the wire frames terminates in a cup containing a drop of mercury, into which the ends of the cross wires from E dip. Connect the cup of mercury E, by means of a wire, with the copper plate of the electromotor (322), either directly or by means of the *inversor* (360), and let the wires CZ, coming from the circular troughs AB, be *both* connected with the zinc plate of the apparatus. Under these circumstances a current of positive electricity will pass from the copper plate to the cup E, and there being divided into two portions will descend the vertical branches of the wire frame, and reach the troughs AB, leaving the apparatus by the wires CZ. Directly the current is in motion, the wire frame suspended on the north pole of the magnet begins to rotate rapidly in a direction from left to right, and that round the south pole, in a contrary direction, from the *reaction* of the fixed magnet on the moveable conducting wires. If the direction of the current be reversed, either by altering the connexions with the electromotor, or by shifting the bars of the inversor, the direction of the rotation will also become reversed.

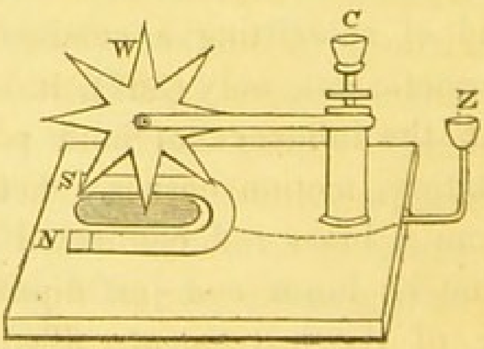
368. The rotation of a conducting wire may be also conveniently shown, by bending a wire into an heliacal coil like a corkscrew, and allowing it to rest by one extremity on the depression on each pole of the horse-shoe magnet (367), the other end dipping into the mercury in the circular troughs AB. On connecting one of these with the zinc, and the other with the copper plate of the electromotor, the current will ascend through one helix, descend the pole of the magnet which supports it up the other pole, and reaching the second helix will descend along it; and thus by the mercurial trough into which it dips, reach the zinc plate of the exciting apparatus. In this variation of the experiment, the heliacal coils of wire will rotate round either pole *in the same direction*, because whilst the positive current ascends in one, it descends in the other.

369. If instead of submitting a conducting wire to the action of one magnetic pole only (367), it be so arranged as to be exposed to the influence of both poles, a vibrating, instead of a rotatory, motion ensues. Let a light wire, W, be suspended from a brass rod connected with the cup of mercury, C, so that its lower end just dips into a cavity cut out in the base of the instrument, filled with mercury,



and connected by a wire with the cup z. Let a horse-shoe magnet be placed, as shown in the figure, and connect c with the copper, and z with the zinc plate of an electromotor (322); the current of positive electricity will descend w, and being acted upon by both poles of the magnet, the wire will tend to rotate to the right, round the *austral* pole, N, and to the left, round the *boreal* pole, S. As it cannot obey both these forces at once, being opposed in direction, it takes an intermediate course, as would be expected, from the law of composition of forces (47), and is thrown forwards out of the mercury, in the direction indicated by the arrow. Connexion being thus broken with the battery, the wire, by its gravity, falls into the mercury, and is again thrown out, keeping up this pendulum-like motion for a long time. Let the direction of the positive current be changed, or reverse the position of the magnet, and a vibrating motion of the wire, in an opposite direction, or backwards, will ensue.

370. If the electric current be made to pass through a spur wheel, w, instead of a wire, a rotatory movement between the poles of the magnet ensues. Thus, if the posi-



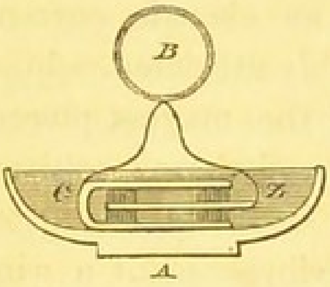
tive current passes from the cup C to the axis of the wheel W, it descends through that spoke which happens to dip into the mercury, and passes from thence to Z, and to the zinc plate of the electromotor. As soon as the current descends the radius of the wheel, the portion dipping into the mercury is thrown out, as in the vibrating wire (369); another spoke of the wheel dips into the mercury, and is thrown out in its turn, and so on, a continual rotatory motion ensuing. If the direction of the poles of the magnet, or of the electric current, be reversed, the wheel will still rotate, but in an opposite direction. The wheel W may be replaced by an entire disc of metal with advantage, as the motion is then more uniform and continued.

371. If a horse-shoe magnet be approached to a suspended rectangle of wire, through whose sides an electric current is passing (365. A,B,C), it will be forcibly attracted, whilst the current is passing, and the poles of the magnet placed in one direction; and repelled, if either of these positions be reversed. This apparent attraction is really owing to the same cause which determines the vibration of a wire suspended freely between the poles of a magnet (369). The rectangle having a tendency to rotate, in common with all conducting wires (367), round the poles of the magnet, in opposite directions, it is compelled, by the law of composition of forces (47), to advance between, or move from, these poles, according to the positions in which they are respectively placed.

372. If the freely suspended rectangle before described (365), through which an electric current is moving, be left to itself, uninfluenced by any opposing cause, it will be acted upon by the magnetism of the earth (220), and will assume a definite position; which it will, if sufficiently mobile, regain when disturbed from it by any applied force. That *face* of the rectangle through which the positive current is moving in the direction of the hands of a watch, always turning towards the south, whilst the other, or that

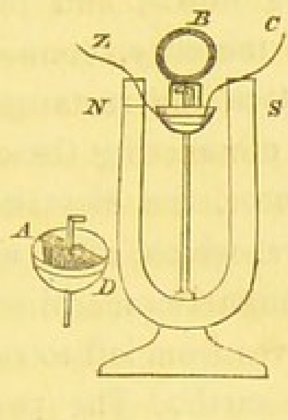
in which the current of positive electricity appears to move from right to left, or opposed to the hands of a watch, will assume the properties of an austral pole, and will consequently point to the northern hemisphere of the earth. Thus in the figure referred to (365), that face of the rectangle ABC, which is there represented, will regard the south pole of the earth; the current of positive electricity moving in it from left to right. If the conducting wire be bent into a circular or other figure, it will present the same phenomena as the rectangle; the shape not influencing its properties.

373. If, instead of using a single fold of wire, as a circle, or rectangle (371-2), several convolutions be employed, its polar phenomena will be proportionably increased. This may be very satisfactorily shown by means of the little apparatus contrived by De la Rive, consisting of a plate of zinc, Z, about an inch square, placed between the folds of a bent plate of copper of the same size. A piece of copper wire, covered with silk, is soldered to the copper plate, and, after being twisted into about twenty circular coils, B, kept close together by means of thread, is fixed by its other extremity to the zinc plate. This apparatus is placed in a shallow wooden cup, A, filled with dilute sulphuric acid, and, on allowing it to float in a vessel of water, the whole will, after a few oscillations, arrange itself in the magnetic meridian. The action of the acid on the plates CZ developing sufficient electricity to cause the coil B to present magnetic phenomena: that aspect, in which the positive current appears to be moving from left to right, regarding the southern hemisphere of the earth. On presenting a magnet towards the coil of wire B, whilst the apparatus is in action, attraction and repulsion will ensue, as if the wire itself had really become a magnet.



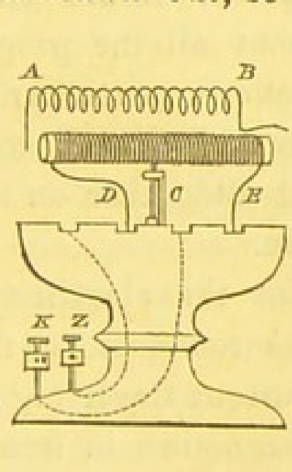
374. The peculiar polar properties of this coil of wire may be beautifully shown by fixing it on a pivot, in the centre of a

shallow circular trough of mercury, divided into two portions by a little wooden partition, as shown at AD. The ends of the



wire coil are pointed, and so long as just to touch the surface of the mercury in the divided box AD, as it, by capillary repulsion (22), rises above the level of the partition without overflowing. On connecting the two cells of mercury, by means of the wires, C Z, with the two plates of an electromotor (322), and placing the whole between the poles of a horseshoe magnet, the wire coil, B, will revolve rapidly, from the two faces of the coil being alternately attracted and repelled by the magnetic poles NS, and the direction of the current traversing it being reversed at each half revolution.

375. The coil of wire used in the preceding experiments may be regarded, as long as the current traverses it, as a *flat* magnet; but if the convolutions, instead of being nearly in the same place, be drawn out, so as to represent a long



helix, its apparent magnetic properties become much more distinct. Let a wire, covered with cotton or silk, be coiled on a glass tube, in a direction from left to right, forming a right-handed helix, and be supported on a pivot, as at C, its two ends, DE, hanging down, and just dipping into two concentric troughs of mercury, connected with the screws, KZ, as in the support of the rectangular conductor before described (365). On connecting these screws with the two plates of an electromotor, the electricity will traverse the heliacal conducting wire, which, after a few oscillations, will arrange itself in the magnetic meridian; that end in which the positive current moves from left to right, pointing towards the south pole of the earth. The two extremities of this helix are respectively attracted or repelled, by the poles of a magnet, as long as the electric current traverses it, as completely as if it were a permanent steel magnet. Ampere, to whom we are indebted for the knowledge of the properties of this and other heliacal conductors, has termed it the *electro-dynamic cylinder.*

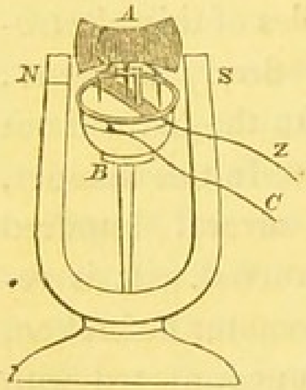
376. The most interesting property of this heliacal conductor, is its power of inducing actual magnetism in a bar of soft iron, placed in its interior. Thus, if a bar of soft iron, in which magnetism is readily excited (213), be placed in the helix, A B (375), and a current of electricity be made to pass through the latter, by connecting its two extremities with the plates of an electromotor, the bar of iron will instantly acquire the power of attracting another piece of iron, and indeed present all the properties of a powerful magnet. These magnetic properties are, however, transient, and are manifested only whilst the electric current is traversing the helix, vanishing altogether on the electricity ceasing to pass through the wire.

As in this experiment the electricity does not *enter* the iron, but merely passes round it in the coil of wire, we learn that an electric current traversing a wire possesses the property of inducing magnetism in iron bars brought within its influence, and placed with their axes at right angles to the direction of the current. If they be not placed in this position, the magnetism induced is proportionably weaker, and at length ceases to be developed.

377. If a bar of soft iron be bent in the shape of the letter U, and be covered with several series of folds of copper wire, insulated by being covered with cotton, and a current of electricity be transmitted through the wire, by connecting its two ends to the plates of an electromotor, the intensity of the induced magnetism will become very obvious. On placing a smooth bar of soft iron opposite to the poles of this *electro-magnet*, it will be attracted, and remain firmly adherent; and an immense weight may be suspended to the bar without separating it from the poles of the magnet. In this manner, *electro-magnets*, capable of supporting several hundred pounds, and even tons, have been constructed. It is remarkable, that if the contact with the electromotor be broken, whilst the poles of the electro-magnet are unconnected with each other, the induced magnetism will, if the iron be very soft, nearly entirely vanish. But if the poles be connected by a bar of soft iron, before communication with the source of electricity be interrupted, a considerable magnetic intensity is left in the curved iron bar, and is permanent so long as its poles are connected, disappearing only on the removal of the piece of iron adhering to them.

378. If bars of hard iron, or steel, be substituted for soft iron, little or no magnetism is developed, so long as the electricity traversing the helix in which they are placed is of low tension. But if a current from a powerful voltaic battery, or the discharge of a Leyden jar (283), be transmitted through the coil of wire, the included bar, if it be small, as a steel needle, becomes *permanently* magnetic, its polar properties not disappearing, as in the case of soft iron, on the cessation of the inducing current. In every case, the *direction* of the poles of the induced electro-magnet bears a constant relation to the course taken by the electric current, and is the same as that in the electro-dynamic cylinder (375).

379. The phenomena of the electric induction of magnetism may be beautifully shown by means of a contrivance of the late Dr. Ritchie, consisting of a bar of soft iron, supported by a pivot, and covered with a coil of insulated copper wire, the two extremities of which just touch the surface of the mercury contained in a circular trough, divided into two cells, by a transverse slip of wood (374). In the marginal figure, NS is an upright horse-shoe magnet, having the bar



of iron A covered with a coil of insulated copper wire, supported by its pivot over the two-celled vessel of mercury B. On connecting the latter by the wires CZ to the two plates of an electromotor, the bar A becomes a temporary magnet, and, if the connexions be properly made, its ends assume the *same* polar state as the poles NS, to which they are opposed; of course, repulsion ensues, and A performs half a revolution: here its wires pass over the wooden partition, and dipping into the opposite cells of mercury, its polarity becomes reversed, and so on; the bar A revolving with immense rapidity, and having its polarity reversed twice during each revolution. During the action of this apparatus, as well as that of the rotating coil of wire (374), a loud humming noise, after amounting to a loud musical sound, is excited by the rapid vibratory motion assumed by the fixed magnet during the rapid revolution of the electro-magnet, or wire coil. This musical sound is remarkably well observed when the magnet is supported by three levelling screws, on a smooth table; and if the apparatus be large, it much resembles the drone of the bagpipes.

380. If the electro-magnet (379) be about four or five inches in length, it will rotate by the magnetism of the earth, independent of any steel magnet in its neighbourhood. Care must in this case be taken to place the bar in the

magnetic meridian, and allow the electric current to traverse the wire coiled round it, in such a direction, that the poles of the temporary magnet may be such as will be repelled by the hemisphere of the globe, to which they are opposite.

381. It has been proved that a conducting wire and a magnet, by their mutual reaction, tend to arrange themselves in a direction at right angles to each other (356, 363), and that if the action of the current, or what comes to the same thing, of the wire conveying it, be limited to one pole only of a magnet at a time, they will tend to rotate round each other in a given and constant direction (366, 367). Wires conveying currents, it has been shown, also possess the properties of mutual attraction, or repulsion, according to the direction of the electric fluid (365), and of being acted upon by the magnetism of the earth, or of a steel permanent magnet, arranging themselves in a constant direction, with regard to the poles of either (371-5). Ampere has extended these facts still further, by showing that two electric currents properly arranged will ever tend to rotate around one another, providing their direction be at right angles to each other. Thus, if a *fixed* current of electricity be supposed to be moving from A to B, as in fig. 1, p. 262, and a *moveable* current be supposed to be placed as in CD, whilst the positive fluid in AB and CD is moving in the direction shown by the arrows, attraction will take place between the currents EB and CD, in the angle CEB; for if CD be inclined towards EB, the currents in each will be moving in the same position (365). Repulsion will be exerted in the angle AEC, between CD and AE; for if CD be supposed to be inclined towards AE, the currents in each will move in opposite directions. If then the current AEB be circular, the moveable current CD will tend to revolve round it.

382. This may be proved by surrounding the circular copper trough *vv*, fig. 2, with some thick insulated copper wire, connected with the binding screws zc. The metallic support s

Fig. 1.

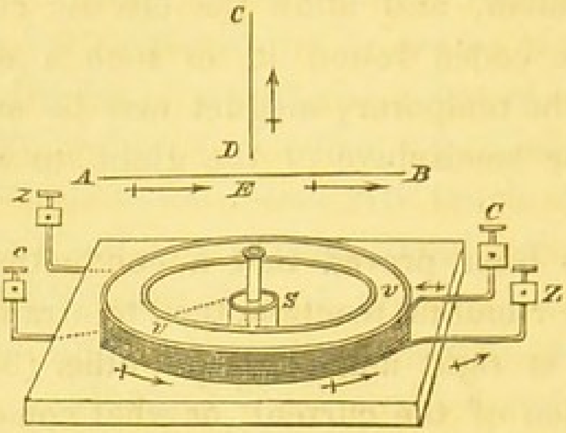
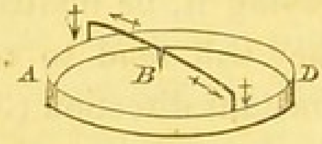


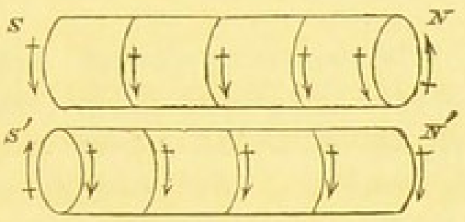
Fig. 2.



is connected, by a wire, with the screw or cup *c*, and the trough V itself with the screw or cup *z*. A light wire frame, ABD, furnished with a hoop or circle of thin copper, is provided with a pivot at B, by which it may rest with as little friction as possible on the support S. Fill *v* with dilute sulphuric acid, place ABD on S, so that its hoop may just dip in the dilute acid in *v*, connect CZ and *cz* to the copper and zinc plates of an electromotor, respectively. Under these circumstances, currents of positive electricity will traverse the wire wound round the trough *v*, and along the frame ABD, in the direction pointed out by the arrows; and the horizontal circular current in the wire acting on the descending vertical currents in ABD, will cause the latter to revolve in a direction varying with the course of the current in the wire surrounding the vessel *v*.

383. From the phenomena detailed in this chapter, a highly ingenious theory of magnetism has been proposed by Ampere, differing altogether from the conventional hypothesis already explained (212), in denying the existence of any magnetic matter as distinct from electricity, and considering that all magnetic phenomena are but the visible effects of invisible electric currents, permeating the iron bars or other substances in which they exist. According to this

theory, every molecule of a magnet must be regarded as being surrounded by a current of electricity, constantly and perpetually circulating around it; and that the only difference existing between a magnet and a mere bar of iron, is simply, that in the latter, the electricity present is in a latent and quiescent state; whereas, in the former, it is in a state of rapid rotation around each ultimate atom or particle of iron. All the effects produced by these elementary currents, may be theoretically represented by a set of resultant currents surrounding the mass, as shown in the following figure. The end N of such a bar will be the austral pole, and point



towards the northern hemisphere of the globe, because there the currents of positive electricity represented by the arrows, are moving in a direction from right to left, or opposed to those of the hands of a watch (372). The opposite end will, consequently, be the boreal pole (214); for, on looking at the face S, as shown at S′, the currents will *appear* to be moving from left to right; for the same reason that a word is seen backwards, on looking at it through the paper on which it is written, by holding the latter between the eye and the light.

384. The attraction between the magnetic poles of different names, and repulsion between those of the same kind (209), is on this theory explained, by supposing that, in the former case, the elementary currents are moving in the same, and, in the latter, in different, directions (365). The rotation of a conducting wire round a magnet (367) becomes also reduced to the simple case of the rotation of a vertical round an horizontal current (382); for all magnets, it must be recollected, are, on this hypothesis, supposed to have myriads of

currents traversing them, in a direction at right angles to a line connecting their poles.

On this theory, also, the magnetism of the earth is explained, by supposing the existence of currents of electricity constantly traversing it in a direction, of the positive, from east to west, and of the negative fluid, from west to east. It must be confessed that, opposed as this view is to the generally received theories, it has received much support from the recent discoveries in electro-magnetic induction (397, 402).

CHAPTER XVII.

ELECTRO-DYNAMIC INDUCTION.

General Statement, 385. *Secondary Currents induced, by Electricity*, 386 —*by Magnets*, 387—*by Electro-magnets*, 388—*in the same Conductor with the Primary Current*, 389—*Calorific effects of*, 390. *Shock from Secondary Currents*, 391. *Currents excited by Revolving Disc*, 392. *Electro-magnetic Machines*, 393—*without Iron*, 394-5 —*with a Permanent Magnet*, 396-8—*with an Electro-magnet*, 400-1. *Theory of Ampere*, 402.

385. Of all the numerous and successful researches made by Faraday, in the different departments of electrical science, none are of greater importance, or more worthy of deep attention and study, than the discovery of electro-dynamic induction, which was made by that philosopher in 1831. As a brief generalization of this discovery, it may be stated that, whenever an electric current traverses a wire, it excites a current in an opposite direction in a second wire held parallel to it; and, on suddenly stopping the *primary* current, the induced one reappears, but in an opposite direction to that which it first followed. Whenever, also, a magnet is moved before a conducting wire in any manner, but especially when the long axes of both magnet and wire are at right angles to each other, similar electric currents are excited or induced in the wire. These *induced* or *secondary* currents are but of

momentary duration, appearing only at the instant the primary or inducing current either effects its passage, or ceases to pass through the wire; and, when excited by the magnet, existing only during the movement of the latter, ceasing the instant it comes to a state of rest.

386. Coil on a wooden cylinder, about two inches long and an inch in diameter, about eight or ten feet of insulated copper wire (*i. e.* covered with cotton or silk thread), and let its two ends project; call these A and B; over this, coil forty or fifty feet of copper wire, also insulated, and separated from the first coil by several folds of silk; call the free ends of this second coil CD. Then connect CD to the screws GG of the multiplier (362), and A to one of the plates of an electromotor (221); suddenly bring B in contact with the other plate, and immediately the needles of the multiplier will move from an induced electric current, traversing the coil CD. This being only of momentary duration, the needles will soon regain their former position: then *rapidly* remove B from the plate of the electromotor with which it was previously in contact, and the needles of the multiplier will again move, but in an opposite direction to that in which they first deviated. In this experiment we see that a current traversing a wire *induces* a secondary one in a wire parallel to it (considering the curves formed by the wires as being constituted of an infinite series of planes), both at the instant of making and breaking connexion with the source of electricity. These currents are always opposed to each other in direction, as proved by the multiplier, and must be considered as arising from *induction*, because the wire traversed by the *primary* or battery current was insulated completely from that in which the *momentary* current, acting on the multiplier, was developed.

387. Coil on a hollow cylinder of pasteboard, half an inch in diameter and three inches long, about fifteen feet of *insulated* copper wire, and connect its two ends to the screws GG of the multiplier (362); then pass into the hollow axis of

this helix a cylindric magnetic bar : instantly the needles of the multiplier will move, showing the existence of a current traversing the coil. Allow the bar to rest in the cylinder, and the needles will return to their primitive position, the induced current disappearing. Suddenly *withdraw* the magnetic bar, and the rapid motion of the needles of the multiplier will indicate the momentary existence of an electric current in a direction the reverse of that, which appeared on *introducing* the bar into the helix. If the opposite pole of the bar be passed into the coil, the induced current will be in opposite directions to that produced by the action of the other pole.

388. Wind round a cylinder of soft iron, or a bundle of iron wire, a few feet of insulated copper wire; let its free ends be called AB. Over this coil, wind about twenty or thirty feet of insulated copper wire, carefully separated from it, and connect its free ends to the multiplier as before (386). On connecting AB to the plates of an electromotor, an electric current will pass through it, and convert the included iron bar into an electro-magnet (258). The magnetism thus set in motion in the bar will, like the movement of the permanent magnet (387), induce a current of electricity in the outer coil connected with the multiplier, and its needles will be powerfully acted on. Then break connexion with the electromotor by removing A or B from the plate with which either was in contact, magnetism will vanish from the iron bar, and an energetic current of electricity in an opposite direction will be excited, causing the needles of the multiplier to deviate with velocity from their former position.

389. A second coil of wire is by no means necessary for the development of an electric current; a single length of *insulated* wire, coiled into a tolerably compact helix, having an induced current excited in it in one direction, on *making* connexion, and another in an opposite direction, on *breaking* connexion with the battery, or other source of electricity. These induced currents, like those before described, are but

of momentary duration, and are always opposed in direction to the primary current; they may be considered as arising from the reaction of the primary current traversing each fold of wire, on the electricity naturally present in the adjoining folds. In this manner is explained the appearance of a vivid flash of light, observed on *breaking* connexion with a small electromotor, by means of a wire folded into a compact coil, whilst scarcely the faintest spark is perceived when a short wire, or long *unfolded* one is used. If connexions be made and broken by means of a cup of mercury, the vividity of the light is increased by reflection from the brilliant surface of the fluid metal, as well as from the latter undergoing combustion by the force of the discharge. If the wire be folded round a bar of iron, the induced magnetism will increase the intensity of the secondary current, and consequent splendour of the spark, on breaking contact with the source of electricity. In this manner are explained the vivid sparks observed during the rotating of a flat coil (374) and of an electro-magnet (379).

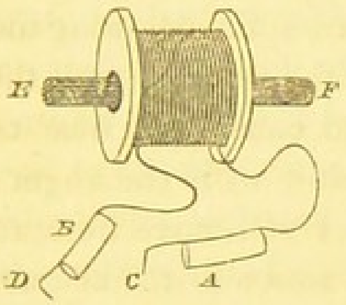
390. If about sixty feet of thick *insulated* copper wire be wound into a short compact coil on a short reel, the effects of these secondary currents may be beautifully observed. The battery employed may be an electromotor of a single pair of plates (322): let these plates be called z and c.

(A.) Connect one end of the helix with z, and fix on c a cup of mercury; introduce the other clean and sharp end of the helix wire into the mercury, and withdraw it with a jerking motion, a vivid flash of light will ensue. The heat evolved is sufficient to inflame ether, or gunpowder placed on the surface of the fluid metal.

(B.) Connect one end of the helix, as before, to z, and fix on c a clean steel file, draw the other end of the wire over the surface of the file, and a succession of reddish sparks, attended with the light arising from the brilliant combustion of the steel, will ensue.

(C.) If connexion with the electromotor be broken by means of the helix arranged as before (B), but with one end of the wire furnished with a piece of leaf-gold or silver, combustion of these metals, attended by the evolution of their characteristic light (338), will ensue.

391. Let about 200 or 250 feet of *insulated* copper wire be coiled on a hollow wooden reel, about two inches long, and furnish each end of the wire with brass or tinned iron cylinders, AB, terminating in metallic points, CD. Grasping these cylinders with the hands, immerse C in a cup of mercury connected with one plate of



the electromotor, and D, in a second, connected with the other plate; suddenly withdraw one of them, as D, and the secondary current thus excited, in completing the circuit from A to B, rushes through the arms of the person grasping them, producing a severe electric shock. If the hands be moistened, to render them better conductors, and connexion be made and broken with the electromotor, by connecting C to one plate, and drawing D over the surface of a file connected with the other (390, B), a rapid succession of very painful electric shocks will pass through the arms and chest of the operator. By placing in the hollow axis of the reel a bar of soft iron, or, still better, a bundle of soft iron wire EF, the intensity of the induced current, the vividity of the sparks, and strength of the shocks, become proportionally increased.

These shocks have been by many persons most erroneously regarded as produced by a single pair of plates, whereas they really arise from a secondary induced current, quite independent of (except that it is excited by it), and far exceeding in intensity, the current originally generated by the electromotor.

392. In all pieces of electro-magnetic apparatus, in which the contact with the battery is suddenly broken, a vivid spark is seen from the induced current excited by the action of the

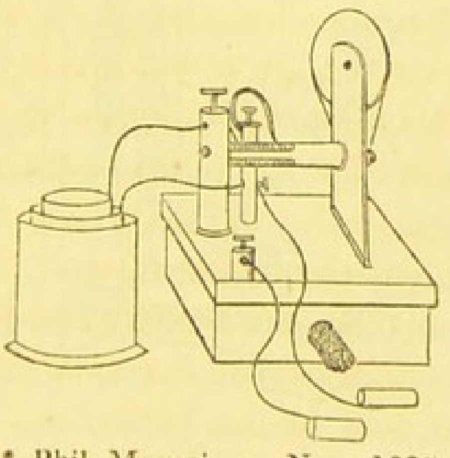
magnet used on the conducting wire. This may be seen in the vibrating wire (369), where each time the moving wire leaves the mercury, a vivid spark is observed; although the electromotor itself may be incapable of affording one. The existence of these currents may be very satisfactorily proved by means of the revolving disc (370), by replacing the stellated wheel W (see fig.) with a disc of copper, so large, that it may just dip into the mercury in the trough. Allowing the magnet to remain in its place, connect the cups ZC with the screws GG of the multiplier (362), and cause the disc to revolve rapidly, by giving it a slight blow with the finger; immediately the needles of the multiplier will move from an electric current excited by the inductive action of the magnet on the revolving disc.

393. The currents thus excited (386-392) are available for all the experiments in which ordinary voltaic electricity is applied, and various pieces of apparatus, termed *magneto-electric* and *electro-magnetic* machines, have been contrived for the purpose of exciting these currents with rapidity. These may be divided into three principal kinds, in two of which an *electric current* is employed as the primary exciting agent; and in the other, a permanent magnet is used.

394. The simplest and most convenient form of electro-magnetic machine is founded on an experiment already described (386), and may be constructed by winding on a wooden reel, about three inches in length, with a hollow axis, about sixty feet of insulated copper wire of about the sixteenth of an inch in diameter, its terminations being soldered to binding screws: this is termed the *primary coil*. Over this, wind about 1300 or 1400 feet of insulated copper wire, about the sixtieth of an inch, or even less, in diameter, and solder its terminations to binding screws: this constitutes the *secondary coil*. If then, the primary coil be connected with the electromotor (322), whilst the ends of the external or secondary coil be held in the hands, on breaking contact with the source of electricity, all the electric fluid present in

the exterior coil is set in motion by the inductive influence of the primary current, and passes through the body of the operator, producing a severe shock : and if the terminations of the long wire dip in acidulated water (350), or rest on paper moistened with a salt, as iodide of potassium, electrolytic action results, and the proximate elements become separated.

395. It is obvious that some means of breaking contact with the battery with sufficient rapidity is necessary to ensure a rapid succession of electric currents; and for this purpose various plans have been proposed. Connecting the *primary* coil to the electromotor through the medium of the vibrating wire (369), stellated wheel apparatus (370), or still better, of the rotating coil (374), or magnet (379), will answer very well, as contact will be effectually broken several times in a second, by their action. I prefer, however, a little apparatus which I have described elsewhere,* consisting of a light iron beam vibrating between two fixed magnets; this enables us to break contact about 400 times in a minute, and consequently affords a rapid succession of currents of induced electricity. Ratchet and cogged wheels have been long employed for the same purpose; but as they involve the necessity of being turned by the hand, they are very troublesome. If any apparatus of this kind be employed, instead of a cogged wheel, a cylinder of wood having two bars of metal inlaid, connected with the electromotor through the *primary coil,* should be used. A brass spring, connected with the

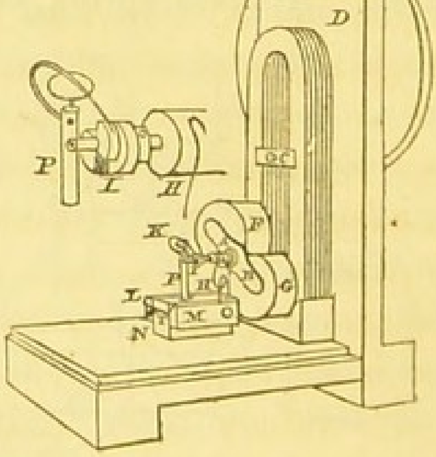


* Phil. Magazine. Nov., 1837.

other plate of the battery, presses upon the cylinder, and on causing the latter to revolve by means of a multiplying wheel, the contact with the battery may be rapidly broken. This is vastly superior to the employment of cogged wheels, which, by their friction, rapidly wear out the spring, and cause a loud and disagreeable noise.

If a bar of soft iron, or, still better, a bundle of iron wire, or a cylinder of tinned iron, be placed in the hollow axis of the *primary coil*, the intensity of the induced currents becomes considerably increased from the inductive action of the magnetism excited in them (388). The machine becoming then a true electro-magnetic machine.

396. Of the magneto-electric machine, in which a permanent magnet is the exciting cause of the currents, there are many varieties. Of these, Saxton's and Clark's arrangements are superior to those of Pixii and others; that of Mr. Clark being upon the whole more convenient than Saxton's, from its small bulk, its intensity of action, and its dispensing with the use of mercury. This consists of an upright compound horse-shoe magnet, pressed against a board, D, by the cross-piece C. By means of a multiplying wheel, E, the armature ABFG is made to revolve rapidly before the poles of the fixed magnet. This armature consists of two pieces of



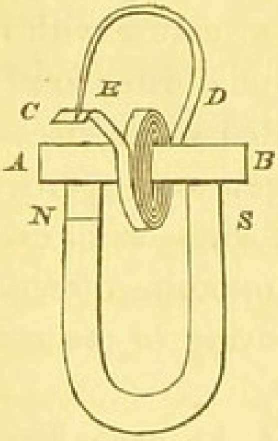
soft iron, connected at right angles to the piece of iron AB by screws; round the legs or branches of this are wound about 1500 yards of fine, *insulated* copper wire; one end of which is connected to a collar of brass, against which the spring H presses, the other end being soldered to an insulated brass collar, I, part of whose circumference has been removed, as shown on a larger scale in the side figure. A thick copper wire, K, presses against I, and is connected by a brass pillar, P, with a metallic strap, L, fixed on one side of the wooden block N, whilst a similar piece of metal, M, with which it is connected by a bent wire, T, is on the opposite side, and supports the spring H. When FG, and consequently their iron axes, are opposite to the poles of the magnet, the latter, by induction, converts the inducted iron into a temporary magnet; at the instant this action occurs, the electric equilibrium of the wire wound round it becomes disturbed, and a current of electricity rushes through the coil. If the armature be turned half round, the magnetism of the iron piece becomes reversed, and a second current in an *opposite* direction is excited; and as at the moment this takes place, the wire K comes in contact with the interrupted portion of the collar I, a bright spark passes between them. On revolving the armature with rapidity, a succession of vivid sparks ensue; and if wires fixed to the brass pieces LM be immersed in acidulated water, decomposition of that fluid will occur, the oxygen and hydrogen gases being evolved alternately from each wire—as of every two induced currents, one is always in opposite direction to the other, the alternate ones only moving in the same direction.

397. If a copper cylinder be grasped in each hand, whilst wires connected with them communicate, one with the strap L, and the other with a cavity excavated in the end of the revolving armature, on turning the wheel E, a rapid succession of currents is sent through the body of the person grasping the cylinders, producing a series of severe and almost intolerable shocks, the muscles becoming

so firmly contracted that he is generally unable to drop the conductors. If the wires, instead of terminating in copper cylinders, be furnished with platina points, electrolytic decomposition of any conducting fluid they are immersed in will ensue, as in the case of the induced current of the previously described apparatus (394).

398. If an armature, having a *short* helix of thick insulated copper wire, be substituted for the armature AB, the intensity of the evolved electric currents will be diminished, and no shock or chemical action will result from them. The vividity of the spark at I will be, however, increased, and pieces of platina wire readily ignited by allowing the electricity to pass through them. The ordinary phenomena of electro-magnetic rotation (367) may be produced by passing these currents from the short helix through the appropriate pieces of the apparatus.

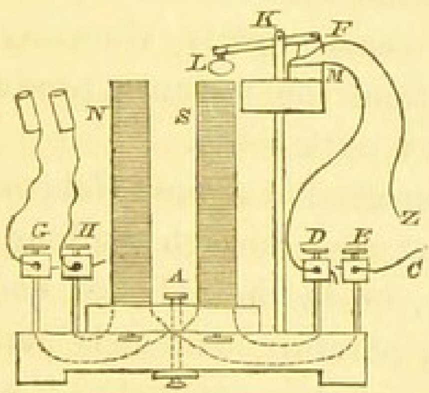
399. A very simple and ready mode of exhibiting the electro-magnetic spark, as it is termed, by the induction of a permanent manget, is to wind round a piece of soft iron AB, about ten yards of thick insulated copper wire or ribbon. Let one end of this coil be soldered to a plate of amalgamated copper C (366), upon which the other end, sharply pointed, is made to press with elasticity; to effect which, it is bent into an elliptical form, DE. On placing this armature on the poles of a strong magnet, NS, the bar AB becomes magnetic by induction (210); and on suddenly *jerking off* one end, as B,



from the pole S, the bar nearly loses all its polarity, and the electric current developed is shown by a vivid spark occurring at the point where E presses on C, as it becomes slightly raised from the plate by the sudden motion communicated to AB.

400. As in these cases the electricity evolved bears a

ratio to the magnetism induced in the iron nucleus of the armatures (396), it follows, that by increasing the intensity of this magnetism, the electric current becomes proportionably increased in tension and quantity; as by means of a current of electricity of low tension we can excite powerful magnetism in an iron bar (376), the application of this as the inducing agent, has been used in the construction of these machines: indeed, it was by a contrivance of this kind, that Faraday first discovered the existence of these currents. The most powerful electro-magnetic machines I am acquainted with are constructed on this principle; the following is a description of one, which I had constructed three years ago: Two bars of very soft iron NS, about fourteen inches long, and an inch in diameter, are connected by a cross piece of iron, A, firmly screwed to them. These bars



are covered with a coil of insulated thick copper wire, about 300 feet in length, the ends of which are connected to the screws DE. Over this are wound about 1600 feet of very thin *insulated* and *varnished* copper wire, its ends being connected to the screws GH.

On connecting DE with a battery of about ten pairs of plates, the iron bars become sufficiently magnetic to lift about sixty pounds weight; and if the copper cylinders, connected to GH, be grasped with the moistened hands, an almost insupportable shock will ensue, on breaking connexion with the battery. To effect this rupture of contact with facility, a contrivance similar to that used by Mr. M'Gauley* will be found very useful: this consists of a beam of brass supported by a horizontal axis at K, having at one end a ball of soft iron, L, suspended, and at the other a fork of thick copper wire, so arranged that by its own weight it will fall into two cups of mercury fixed at M, and thus connect them with each other. One of these cups is connected by a wire with the screw D, whilst the other is, by a wire Z, connected with one end of the battery, the screw E being in communication with the other. As soon as these connexions are completed, the bar S, becoming magnetic, attracts the ball L, which, falling, raises the fork M from the cups; thus breaking contact with the battery, and producing a vivid spark attended with a loud snap, and combustion of the mercury. The bars losing their magnetism, the fork F falls by its own weight, and re-establishes connexion with the battery; L is again attracted, and so on, the beam rapidly vibrating amid a complete shower of sparks from the mercury, producing a most brilliant spectacle in a dark room.

401. A rapid succession of powerful currents being at each rupture of contact sent through the long coil, the shock felt at the screws GH, or at the cylinder connected with them, becomes intensely painful, completely paralysing the arms of the persons grasping the conductors; with these currents evolved at GH, chemical decomposition may be performed and other effects produced, as with a voltaic battery. If a piece of charcoal (336) be placed on G, and a platina wire connected with H be placed against it, whilst the machine is in action, a series of minute sparks from the induced currents will be observed.

402. As electric currents are induced by other currents passing *near* the conductors, in which they are excited, the theory of Ampere (383) receives considerable support from the facts enumerated in this chapter. Granting with him

* Rep. British Association, vol. vi., p. 24.

that a magnet is full of perpetually moving currents of electricity, it induces magnetism in a bar of iron, by exciting similar currents, as in the case already mentioned (386), and then the remarkable fact of magnets exciting electric currents in wires moved near them, will be resolved into the same case of currents exciting currents. In fact, it permits us to generalise the phenomena of magnetism and electro-dynamics, in a very important and satisfactory manner. The apparently mysterious phenomena produced by revolving plates of different metals under magnetic needles, in causing them to move, may be referred to a similar explanation ; the currents in the needles exciting similar currents in the revolving plate, which by their reaction on the needles cause it to oscillate and revolve.

CHAPTER XVIII.

THERMO-ELECTRICITY.

Excitaton of Thermo-electric Currents by two Metals, 403—*by one Metal unequally heated*, 405—*Rotations produced by*, 406—*Chemical Decompositions, and Sparks from Currents induced by*, 407. *Currents evolved by Metals plunged into Fused Salts*, 408.

403. When two different metals, as copper and bismuth, are soldered together and connected by wires to a multiplier (362), a powerful electric current becomes developed on heating the point of juncture of the two metals with a spirit lamp. If the multiplier be sufficiently delicate, the deviation of the needles will occur when the point of connexion of both metals is grasped in the hand; a very slight elevation of temperature being sufficient to produce this effect. In general, the most powerful currents are evolved by heating the more crystalline metals, as bismuth and antimony; and they increase within certain limits with the increase of temperature. The following list contains the names of several metals, any two of which being employed as a source of electricity, by heating them at their point of junction, currents are developed in such a manner that each metal becomes positive to all below, and negative to all above it, in the list:

+ Bismuth
Platina
Mercury
Lead
Tin
Gold
Silver
Copper
Zinc
Iron
— Antimony.

404. This mode of developing electricity was discovered in 1821, by Prof. Seebeck, of Berlin, and has been studied with success by Prof. Cumming, of Cambridge, Mr. Sturgeon, and many other philosophers. In examining these currents, as they are of too low intensity to force their way through very long conducting wires, the multiplier should be constructed in the manner already explained (362), but the wire coil should be short, and composed of thick and soft copper wire, so as to offer as little opposition as possible to the passage of the currents.

405. It is by no means necessary to employ two metals in these experiments, for if two pieces of copper wire be twisted together, and connected with the multiplier, a current of electricity takes place on holding a spirit lamp on one side of the juncture. Even platina and gold wires will evolve these currents; so that they are to be regarded as arising from a series of decompositions and recombinations of electricity produced by the action of heat, and not resulting, at least necessarily, from oxydation or other chemical action. When an uniform bar of metal is heated at one end, the cold portions assume negative and the hot ones positive electricity.*

406. The phenomena of electro-magnetic rotation may be readily produced by means of thermo-electric currents; for this purpose twist round each end of a bar of bismuth an inch in length, a thick copper wire, and having amalgamated (366) their other ends, immerse them in the circular troughs AB of the apparatus for the rotation of a conducting wire round the pole of a magnet (367). Apply a spirit lamp to one end of the bar of bismuth, and as soon as the latter becomes warm, a current of electricity will pass through the apparatus from the copper to the bismuth, and the conducting wires suspended on the poles will begin to revolve with rapidity.

407. The intensity of the evolved electricity increases by

* Becquerel, Traité, tom. i., 234, ii. 35.

combining a series of alternations of two metals, as copper and platina, or bismuth and antimony, as in the ordinary electric pile (330). And by the current excited by a large number of alternations of platina and iron, M. Botto*, of Turin, succeeded in decomposing water and various saline solutions. In 1836, Chev. Antinori† of Florence, by connecting a thermo-electric battery with an helix of insulated copper wire, about 500 feet in length, obtained on breaking contact a vivid spark from the induced or secondary current produced by the passage of the primary thermo-electric current (390). Shortly afterwards, Prof. Wheatstone‡ repeated this experiment with success, using a battery of thirty-three pairs of bismuth and antimony, forming a cylindrical bundle, 1·2 inches long, and 0·75 inch in diameter, with a coil of *insulated* copper ribbon 50 feet long, and 1·5 inch broad Mr. Watkins§ has since obtained the same results, by using a single pair of plates of bismuth and antimony, each being 0·5 inch long, 0·12 inch thick, and weighing but five grains. The same gentleman, by using a thermo-electric battery of thirty pairs, each plate being 1·5 inch square, and 0·33 inch thick, and heating one end of the arrangement with a hot iron, whilst the other was kept cool with ice, succeeded in exciting an electro-magnet to such an extent as to support a weight of ninety-eight pounds.

408. Dr. Andrews,|| of Belfast, has discovered that platina wires connected with a multiplier, and plunged into fused salts, are traversed by an electric current. This may be shown by connecting a piece of platina wire with one screw of the multiplier (362), and bending its free end into a loop. On fusing a little borax in the loop, by means of the blow-pipe, and quickly inserting the previously *heated* end of a second platina wire also connected with the multiplier, into

* Bibliothéq. Univers., tom. xxxiii. p. 259.
† Indicatore Sanese, Dec. 13, 1836.
‡ Phil. Mag., x. p. 414.
§ Phil. Mag., vol. xi. pp. 304, 399.
|| Ibid, vol. x. p. 433.

the fused bead, the needles flew to the extreme of the scale, from the development of a powerful current. The direction of the positive current appears to be from the hot platina wire, through the fused salt to the cold wire. By means of these curious thermo-electric currents, Dr. Andrews succeeded in obtaining distinct evidence of chemical decomposition. The same results were obtained when other fused salts, as carbonate of potass, chlorides of potassium and strontium, iodide of potassium, sulphate of soda, and even boracic acid, were used.

CHAPTER XIX.

ORGANIC ELECTRICITY.

409. Certain fishes have, from remote antiquity,* been well known to possess the property of communicating a numbing sensation to persons who have incautiously grasped them. This remarkable effect, whose intensity is sometimes so great as to amount to a severe shock, has been most satisfactorily traced to electricity; and no real difference exists between the electric fluid thus *secreted, or excited* by these animals, and any of the other modifications of that curious form of imponderable matter already described. The fishes hitherto met with, which possess this extraordinary faculty, are but few: of these the torpedo ocellata and marmorata are alone met with in Europe. The others, including the gymnotus, tetraodon, silurus, rhinobatus, and trichiurus electricus, are confined to the tropics. The torpedo, gymnotus, and silurus have been submitted to very careful investigation: the first, chiefly by Hunter,† Dr. John Davy,‡ Gay-Lussac,§

* Aristotle, Hist. Anim., lib. ii., cap. 13, and ix., cap. 37. Pliny, Hist. Nat., lib., xxxii., c. 1. Ælien, de animal. natura., lib. i., cap. 36, &c.

† Phil. Trans. 1773. ‡ *Ib.* 1832 and 1834.

§ Ann. de Chim., lxv., p. 15, joint paper with Humboldt.

Colladon,* and Matteuci;† the second, by Rudolphi,‡ Walsh,§ Ingenhouss,¶ Humboldt,|| Bonpland, and Faraday,** and the last by Rudolphi††, and Müller.

410. The electric organs of the torpedo lie on each side of the head and branchiæ; being made up of numerous five or six sided prisms, placed in such a manner as to present their bases to one surface of the fish, and their apices to the other; Hunter counted 1182 of them in a single organ. They are divided horizontally, by numerous septa, the interspaces being filled up with a gelatinous fluid. These organs are copiously supplied with nerves, which are chiefly branches of the par vagum, or pneumo-gastric nerves. The power of communicating the shock depends upon the integrity of the nerves, for the heart may be cut out, and the animal flayed, without its losing this faculty; but as soon as the nerves are divided it vanishes entirely. The intensity of the shocks are increased by irritating the origin of the electric nerves with the point of a knife. The electric discharge is directed from one surface of the fish to the other, the electricity of the dorsal surface being positive, and that of the ventral negative; and no shock is experienced unless direct, or indirect, communication is made between the belly and back of the animal. A complete separation of the two electricities on the two surfaces does not occur, as that portion of the animal nearest the electric organs is positive, or negative, ac-

* Séances de l'Acad. de Sciences, Octob. 1836. † *Ib.*

‡ Abhand. der Acad. v Berlin, 1820, 1821.

§ Phil. Trans., 1774.

¶ Vermischte Schriften, p. 272. Vienna, 1782.

|| Phil. Trans., 1839.

** Abhand, Acad., Berlin, 1824.

†† Handbuch der Physiologie des Menschens, i., p. 66, Coblenz. 1837; or Bailey's translation, London, 1837.

The Tetraodon is described by Paterson in Phil. Trans., 1786, p. 382. The Trichiurus is figured by Willoughby, in his Icthyology; Appendix, t. 3, fig. 3; and described by Nieuhof in "Zee on Lant Reise door West en Ost-Indien," p. 270, Amsterdam, 1682.

cording to the particular surface, with respect to those parts nearer the tail. Dr. Davy succeeded in decomposing acidulated water, and iodide of potassium, as well as of heating but not igniting platina wire, and of magnetising needles placed in a spiral coil of wire, by means of currents from the torpedo.

411. In the gymnotus, the electric organs are double, and extend on each side from the head to the tail. They are each formed of long horizontal membranous structures, placed at a short distance from each other, provided with numerous transverse septa, and filled, as in the torpedo, with a gelatinous fluid. These organs are supplied by spinal nerves, in which respect it differs from the last described fish ; these consist of 224 pairs of intercostal nerves.

The gymnotus resembles an eel in appearance, and is often four and five feet in length ; its shock is extremely strong and capable of paralysing horses and mules. Walsh and Ingenhouss, in 1776, observed a spark to pass between two pieces of tinfoil through which the discharge of this eel was transmitted. This was doubted until in, 1836, the power possessed by electric fishes of yielding a spark was again asserted by Linari ; and within the last year this statement has been placed beyond a doubt by the researches of Faraday, who, availing himself of the electric eel publicly exhibited at the Adelaide Gallery, succeeded in obtaining a current of sparks, and all those effects which are characteristic of ordinary voltaic electricity.

412. The silurus is still less known than the gymnotus ; its electric organs are, as in that fish, double, and are separated by a tough aponeurotic membrane ; the most external of these organs lies immediately under the skin, the deeper one being imbedded in the muscles. They are both divided into cells ; their nerves are, it is remarkable, the same as both the torpedo and gymnotus, one of the organs being supplied by the pneumo-gastric, the other by the intercostal nerves.

413. In the electric fishes the power of *secreting* electricity resides in a particular structure; but a remnant of this power is observed in certain animals, especially among the *batrachians*, in which no supplementary organ of this kind is to be met with. At least, such a trace of a power of disturbing the electric equilibrium of the system, appears to reside in frogs and other animals, characterised by an intense degree of irritability to the stimulus of electricity. When frogs are used for this purpose, they should be employed in the spring, when they possess their highest degree of irritability; and *prepared*, by removing the skin from the legs and thighs, cutting them off from the body, and leaving as large a portion as possible of the sciatic nerves projecting.

Place the prepared legs of a frog on the table, holding a piece of zinc in one hand, bring the metal in contact with the sciatic nerves, and with the finger of the other hand touch the muscles of the leg; immediately a violent contraction will ensue.

If this experiment be repeated with a piece of iron, instead of a piece of zinc, the same contraction will occur; and to the accidental observance of this fact by Galvani, professor of anatomy at Bologna, in 1790, we owe the discovery of galvanic and voltaic electricity.

It was, in opposing the theory proposed by Galvani, who supposed the electricity to be evolved by the vital functions of the animal, that Volta was led to make those great discoveries that led to the knowledge of that important science which so deservedly bears his name. (Chap. xv.)

414. A far more satisfactory experiment, as proving the development of electricity in frogs—at least if the production of muscular contraction can be considered as conclusive on that point—is to place the prepared leg of a frog (413) on a glass plate with the nerve hanging down. By means of a piece of wood, or glass, bring the truncated end of the nerve in contact with the muscles of the leg, and an immediate con-

traction of the latter will occur, if the frog has been lately killed, and possesses its usual irritability. Müller found that the same thing occurred when the nerve and the muscle were connected, by means of a dead or living frog, or even by a putrescent limb of one of those animals. This experiment generally succeeds best if performed on a frog just before the spawning season.

415. Among invertebrate animals, a few have been stated to have claims to be considered as electrical, but this is extremely doubtful. Molina* relates that a certain Chilian spider possesses the property of benumbing the hand of the person who touches it. Kirby and Spence† mention a species of cimex, the *reduvius serratus*, as having the power of communicating electric shocks. An account is on record also, of one of the great marine annelidæ, *leonice gigantea*,‡ giving a powerful shock to the person who touched it.

416. With regard to the presence of electric currents circulating in warm-blooded animals, evidence is by no means so satisfactory, as in the case of animals of lower organization; a solitary instance is on record by Cotugno§ of Milan, of a case in which shocks were given by a mouse dissected alive. Aldini, the nephew of Galvani, succeeded in producing contractions in decapitated animals, merely by communicating their nerves and muscles by means of his own body; but these researches have not been repeated, and much obscurity still shrouds the whole subject. From some very late experiments of Matteuci, it appears tolerably certain that electric currents, capable of being detected by the multiplier, exist between the liver and stomach of newly-killed animals; these currents disappear entirely, on dividing the spinal marrow. Dr. Donné found that by placing a

* Naturgeschichte von Chili, p. 175.

† Introduction to Entomology, 1, p. 110.

‡ Silliman's Journal, xv., 357.

§ Lichtenberg, Magazin für das neüste aus der Naturkunde, viii., 121.

plate of platina in connexion with the multiplier, on the surface of the skin, and a second also communicating with that instrument in the mouth, the needles moved, from the existence of a positive current, passing from the moist cutaneous surface to the lining membrane of the mouth.

416.* Pouillet fancied that he had succeeded in detecting free electricity circulating in the nerves, but his experiments are inconclusive. Very lately, Professor Prevost has stated, that by transfixing a nerve with a steel needle, and irritating the animal so as to cause contraction of the limb, the needle becomes magnetic by the consequent electric disharge. Still further researches are required before this statement can be regarded as beyond a doubt.

417. Many persons, with Hunter, Abernethy, Proschasca, &c., have felt inclined to regard electricity as the cause of most, or all of the functions of life; but no one has carried this to such an extravagant length as Meissner. This philosopher has asserted that, during respiration, blood acquires electricity, which becomes distributed by the pneumo-gastric and sympathetic nerves to the great nervous centres. Thus becoming charged, the brain excites the action of any organ by giving a spark to the nerve supplying that structure. The electric fluid thus sent to the muscles forms around each of their molecules a kind of atmosphere; thus becoming similarly electrified, the fibres repel each other, separating in the middle of the muscle, and approximating their ends in a similar manner as in the experiment of the electric threads (275, E). This theory beautifully illustrates the well-known remark of Cicero, " that nothing can be imagined so absurd, as not to find a supporter among philosophers."

418. It is quite indisputable that the human body is always in an electric state, but of the feeblest tension, never exceeding that evolved by the contact of a plate of zinc with one of copper (317). It increases with the irritability of the person, and appears to be greater in the evening than in the

morning, disappearing altogether in very cold weather. Pfaff and Ahrens,* to whom we owe most of these observations, have also observed the electricity to be increased after partaking of spirituous potations, and to be generally positive. Women are stated to be not unfrequently negative, especially during pregnancy. Hemmer, a German philosopher, in 2422 experiments on himself, found his electricity to be in 1252 trials positive, in 771 negative, and in 399 he could not detect a trace of free electricity.

419. Various accounts are on record of a large accumulation of electricity taking place in the human body, to the great inconvenience of the person possessing this peculiar property; but on investigating such reports, they may generally be traced to disturbance of electric equilibrium by friction, or other causes. Thus Cardan relates the case of a Carmelite monk, whose hair emitted sparks whenever it was stroked backwards; in which there is nothing very wonderful, for if the hair be dry, any one, especially in frosty weather, by drawing a comb through it in a dark room, will observe a plentiful evolution of sparks. Even in very unfavorable weather, if a person stands on an insulated stool and connects himself with a condenser connected with an electrometer (239, 298), and any one standing on the floor draws a comb rapidly through his hair, the gold leaves of the electrometer will diverge to their utmost extent, on drawing back the uninsulated plate of the condenser. In this experiment, by the act of drawing the comb through the hair, electric equilibrium is disturbed, the body being left in a positive state, the comb taking the free negative electricity.

Fire is said to have streamed during sleep from the head of the Roman King Servius Tullius; and a late writer has suggested that the flame related by Virgil to have played

* Meckel's Archiv., iii., 161.

round the head of Ascanius, was electric; although perhaps the whole story was a poetical fabrication.

> Ecce levis summo de vertice visus Juli
> Fundere lumen apex, tractuque innoxia molli
> Lambere flamma comas, et circum tempora pasci.
>
> Æneid, ii., 682.

420. The vital functions of vegetables appear to be frequently attended with a disturbance of electric equilibrium, sufficient to evolve even sparks, at least if we are to believe reports on this subject. Pouillet has satisfactorily proved that electricity is evolved during germination, and Dr. Donné has shown that electric currents are to be detected in all ripe fruit, passing between their bases and apices.*

From a few observations made by myself on this subject, I arrived at the following conclusions :

1. The great improbability of vegetables, on account of their feeble insulation, even becoming so charged with electricity as to afford a spark, and the probability of those luminous phenomena said to be exhibited by some plants, depending on other sources than electric currents.

2. That electric currents *of very feeble tension* are always circulating in, and exerting their influence upon, vegetable tissues in every stage of their development.

3. That electric currents are developed during germination, and assist in producing the important chemical changes proper to that process; and that by causing the seed to assume an oppositely electric state, we retard or check its development.

NOTE.

On the subjects treated of in this chapter, the student should refer to Becquerel, Traité, vol. iv.; and to the first volume of Müller's Physiology. The Traité complet de Physiologie, of Tiedemann, contains some interesting information on this subject in the second volume.

* Magazine Nat. Hist., N.S., I., 296.

CHAPTER XX.

UNPOLARIZED LIGHT.

(THEORETICAL CONSIDERATIONS AND CATOPTRICS.)

421. Over the actual nature of light, some doubt and obscurity still remains, notwithstanding the innumerable observations that have been made upon it. Passing over the theories, or rather vague ideas, of the ancients, we find three different hypotheses have, in modern times, attracted most notice. The first, and until within the last few years almost universally adopted, was that of Newton; according to whom, light consists of an emanation of infinitely minute particles of matter, thrown off from the sun and other self-luminous bodies, with an enormous velocity, and capable of exciting similar emanations from bodies upon which they impinge, and by which such bodies are rendered visible. The second theory, being that toward which philosophers of the present day generally incline, is a modification of one proposed by

Descartes, and adopted by Huygens, Euler, and our late talented countryman, Dr. Young. This hypothesis regards light to be the result of undulatory or oscillatory movements, in the ethereal or imponderable medium, filling up the interstices existing between the molecules of ponderable matter, and extending into space, beyond the confines of our atmosphere. This undulatory theory, as it is termed, is capable of affording a ready solution to certain phenomena, to which the Newtonian hypothesis of emission is, at least at present, to a great extent inapplicable, and, on that account, has received the support of most philosophers of the present day. The third theory, proposed by Oersted, regards light as the result of a series of electric sparks: this has met with but few supporters.

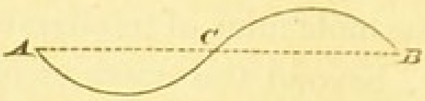
422. According to the undulatory theory, the evolution of light is supposed to be produced by the oscillations of the universal ethereal medium, existing in the interspaces between the atoms of every material substance, and extending beyond the confines of our atmosphere into infinite space,* in the same manner as sound is produced by the vibrations of the denser medium, or air, constituting our atmosphere. The movements thus excited in the eminently subtle and elastic medium,† or ether, are readily communicated to what is ordinarily termed a vacuum, but which is really filled with this imponderable matter, as well as to transparent bodies, by causing their particles, as well as those of the interstitial ether, to assume an oscillatory movement. The ethereal medium contained within the interstitial spaces of transparent bodies is less elastic than that contained in vacuo, and this elasticity appears to diminish with the increase of the refractive power (445) of the substance.

The, so called, undulations of an eminently elastic fluid, like ether, differ considerably from those of a comparatively

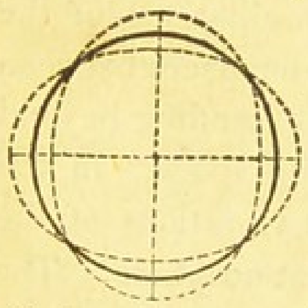
* *Vide* Introductory Discourse.

† *Vide* Wellenlehre auf Experimente gegrundet; Von Heinrich und Wilhelm Weber. p. 564. Leipzig, 1825.

inelastic fluid, as water, and require some explanation, without which some of the following remarks will appear obscure. In a nearly inelastic fluid, as water, a wave excited in it consists



of two portions, one, AC, descending, the other, CB, ascending; each of these portions are said to be in opposite *phases;* and if two waves in the same phase act upon an atom of fluid, they will excite a wave equal in extent to their *sum;* and if they be in opposite phases, to their *difference* (486). In highly elastic fluids, each particle, which is assumed to be spherical, oscillates laterally rather than undulates; so that it becomes



alternately extended and depressed at its poles and equator, as in the case of the elastic ball of ivory before described (9). In this lateral oscillatory trembling motion of the particle of elastic fluid, its extension in one direction corresponds to the phase of elevation, CB, of the wave of water; and its phase of contraction, in the same direction, to the depression, AC, of the same wave. Thus, the movements of luminous ether are rather trembling, or oscillatory, than undulatory. And such movements become communicated to distant particles without the intermediate ones becoming moved from their places, in a manner similar to that in which an impulse communicated to the first of a row of ivory balls acts on the terminal one, and causes it to assume motion, (70, 71,) the intermediate balls remaining unmoved.

423. The waves of light, like those of sound (177), are transmitted in every direction, extending on every side of the luminous body, with an intensity inversely as the square of the distance (180). Whilst sonorous vibrations are conveyed to the ear, through the atmosphere, by the particles of air composing the latter assuming a similar wave-like move-

ment, the luminous body, as the sun, or a lamp, by exciting an analogous undulatory movement (422) in the universal ethereal fluid, (which, becoming conveyed by contiguous particles, eventually reach the eye,) communicates the sensation of light to that organ, in the same manner as sonorous vibrations convey the sensation of sound to the ear. Thus, the cessation of undulations, or repose of the ether, produces darkness; as the absence of similar movements in the air produces silence. It has been objected to this theory, that if true, light ought to bend round opaque obstacles, in the same manner as the waves of water find their way round fixed obstacles, and be communicated through curved tubes, like sound, and consequently that no true shadow ought to exist. These objections, however, are more apparent than real; for, taking the case of sonorous vibrations, we find that they do not bend round obstacles with facility, and that an acoustic shadow does really exist. Thus the sound of a rapidly moving carriage becomes much less distinct as it turns the corner of a street; and sounds passing through water are still more readily obstructed (187). The existence of an acoustic shadow may be better shown by vibrating a tuning fork, and holding it about six inches from the ear; suddenly interpose a piece of card between the latter and the sounding body, instantly the tone will disappear, and on withdrawing the card will again become audible, and so on. In the case of curved tubes, we know that whilst sonorous undulations are readily transmitted through them, those of light are completely excluded; for no one can see through a bent brass pipe. But, in this case, it must be recollected, that the sides of the tube, whilst they are sufficiently smooth to *reflect* sound and to assume sonorous vibrations, are infinitely too rough and too inelastic to reflect, or to assume undulatory movements sufficiently rapid to produce light. There is no difficulty in seeing objects through a tube bent twice at right angles, providing four plane mirrors are properly placed in its interior; and it is certainly at least possible, that bodies are not visible through bent tubes, because the opaque substances of which they are composed stifle, and check any luminous undulations (422) that may attempt to enter them. Lastly, whilst sonorous undulations are thus shown to pass round inelastic obstacles with extreme difficulty, those of light are capable of, to a certain extent, passing round the edges of opaque bodies, and entering their shadow, as shown in the phenomena of *inflection* or *diffraction* (489). Luminous undulations, (or, in other words, light,) become propagated from the sun to the surface of our globe, with an enormous velocity, at the rate of about 191,515, or, in round numbers, 192,000 miles per second ; and this motion is the same for light evolved from the most distant fixed star as for that from the nearest self-luminous body.

424. All bodies may be divided into those which are self-luminous, i.e., capable of exciting luminous undulations of themselves, as the sun, or a lighted lamp; and those which are *opaque*, and only become luminous in the presence of the former: thus the moon and planets are opaque bodies, and are luminous only in consequence of the presence of the sun about which they revolve. A great number of bodies possess the property of intercepting the passage of light, and thus producing a shadow by obscuring the substances from which they intercept the luminous undulations. These shadows are, in general, bounded by right lines, or present the same figure as the sections of the intercepting bodies, in consequence of the difficulty of luminous undulations extending round obstacles. Such bodies as permit light to pass through them are termed *transparent*, in opposition to those which intercept it, constituting *opaque* substances.

425. Non-luminous bodies become luminous in the presence of self-luminous substances,—either, if sufficiently smooth, by reflecting the undulatory movements back into the ethereal medium, or, by having vibrations excited in the imponderable matter contained therein, which, if sufficiently rapid, become communicated to the surrounding ethereal atmosphere. Thus

then bodies are not rendered visible by anything giving off from a luminous source, and impinging upon them; but, by the undulatory movements arising from the alternate condensation and expansion of ether communicated to contiguous particles, and thence to the opaque body, whose included imponderable matter assumes a similar movement, and thus the body becomes in its turn a source of fresh luminous undulations.

426. If the surfaces or internal structure of substances be arranged in a certain manner, the luminous undulations produced by it in the presence of a self-luminous body will communicate to the eye the sensation of *white* light; but if it be so constructed as to check all the luminous undulations which act upon it, it cannot become the source of a fresh set of analogous movements, and is said to be *black.* We know that in the Æolian harp the strings assume different states of vibration, and evolve corresponding sounds, when acted upon by a current of air, according to the diameter and tension of the cords (194); the tightest and thinnest string evolving the sharpest, the loosest and thickest the lowest note. In a similar manner* are the undulations arising from any source of light supposed to be affected by the physical structures of bodies, by which the elastic ethereal medium contained in some assumes undulatory movements analogous to the tightly-stretched cord in the Æolian harp, and thus communicate to the eye the sensation of violet or purple light; whilst the particles of ether contained in other substances under similar influence, oscillate with a less degree of velocity, and convey the idea of *red,* on reaching the eye. The rapidity of the undulatory movement assumed and propagated by coloured bodies does as infinitely exceed that of sonorous vibrations as the density and elasticity of ether do that of the air. Thus, whilst to evolve red light, a body must communicate to ether about 477 millions of millions, and to evolve violet, not less than 699 millions of millions of undulations in a second;

* *Vide* Euler's Letters, *supra citat.* Vol. i., let. 19, et seq., and vol. ii. *passim.*

the lowest note, or C of the fourth octave from the base (196), is produced by 258, and the highest, or C of the next octave, by but 516 vibrations in a second of time.

Colours are consequently no more *innate* or *abstract* properties of bodies than any particular sound or note is; the latter varying with the tension, length, and thickness, of the substance, and the former with certain, perhaps analogous, variations of physical structure.

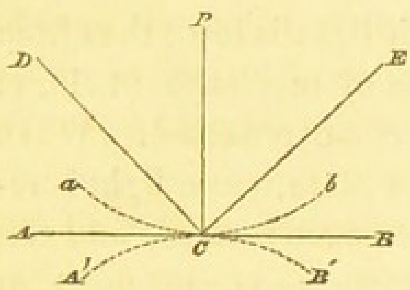
427. Luminous undulations are produced by every portion of a body, and vary in their rapidity with the colour of the substance: thus, if a small hole be made, or, still better, a convex lens be fixed in one end of a wooden box, blackened internally, and it be presented towards any object or landscape, an inverted image will be painted upon a piece of white paper, fixed at the opposite end, and presenting the very same lines as the object of which it is the image (559).

428. A ray of light on the undulatory hypothesis is a right line extending from the luminous body to the limit of the sphere of undulation; and consequently, in the direction in which the body is visible. To such rays, the undulations producing them are perpendicular; they therefore must be considered as merely expressing the direction of *an effect*, and not, as on the Newtonian hypothesis, as causes or sources of light.

429. When a ray of light falls upon the surface of any substance, it may undergo one or more of the following modifications: A, It may be *reflected* back into the medium in which it was moving (431); B, it may pass into the substance and be *refracted* (443), still retaining its original characters; or may, C, be divided into two portions, each possessing distinct physical properties (507); D, a ray has become absorbed by having the undulations producing it checked (475); or may, E, excite a fresh set of undulations, and consequent rays, on the surface of the substance, thus rendering it visible; F, it may also, by meeting with a second ray, have its intensity modified by their mutual *interference* 486); or, G, during its refraction, or reflection, or partial

absorption, acquire new properties, characteristic of polarized light (517); and lastly, have the rapidity of the undulations producing it so affected as to give rise to the phenomena of colours (467).

430. When luminous rays proceed from a very distant body, as the sun, they may be regarded as *parallel;* when they are given off from a point, extending as they proceed, they are termed *divergent;* and when they gradually approach each other, as after being acted upon by a concave mirror or convex lens, they are said to be *convergent.* The intensity of light does not depend upon its colour, but bears a ratio only to the amplitude of the undulations producing it: some approach to a comparative measurement of it, may be obtained by ascertaining the squares of the distances at which any two sources of light, as two candles, require to be placed, to cast upon a wall, shadows of a rod of wood or metal, of equal intensity; these numbers will be to each other in the ratio of the intensity of the light evolved from the two candles.



431. Whenever a ray of light falls upon a plane polished surface capable of reflecting it, it obeys the same law as that of moving elastic bodies (46), the angle of incidence and reflection being equal. Thus, let AB be the surface of a plane mirror (432), and DC a ray incident upon it; draw the perpendicular P, and DC will be reflected in the direction CE, forming the angle PCE, equal to the angle PCD; the latter being the angle of *incidence*, and the former that of *reflection*. If, instead of the ray being incident on a plane, it had encountered a curved surface, it would have obeyed the same law, and be reflected at the same point as from a plane, which would be a tangent to the curve at that point. Thus, if the ray DC were incident upon the concave surface *ab*, or the convex one A′B′, it would still be reflected from C in

the same manner as if it were incident upon a tangent to either curve at C, or ABC. The lines DC, PC, and EC, or the direction of the incident and reflected ray, will always be in the same plane with the perpendicular.

431.* A considerable proportion of the luminous undulations become checked on impinging upon the reflecting surface, thus the intensity of the reflected light is never equal to that to the incident; this loss diminishes with the obliquity of the incidental rays. M. Bouger has given the following table of the proportion of incidental to reflected rays at different angles from the surface of water and of glass; the number of incidental rays being supposed to be 1000:

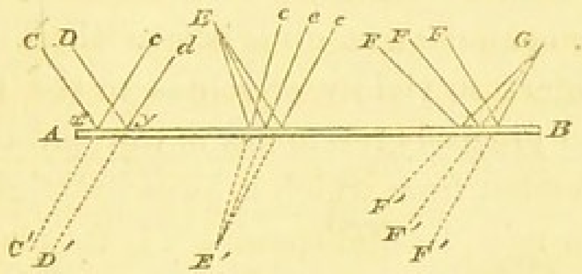
Angle of incidence.	Surface of water.	Surface of glass.
85 . .	. . 501 . .	. . 549
80 . .	. . 333 . .	. . 412
75 . .	. . 211 . .	. . 299
40 . .	. . 22 . .	. . 34
20 . .	. . 18 . .	. . 25
0 . .	. . 18 . .	. . 25

Even when reflected from the surfaces of the most perfectly polished metallic mirrors, much light is lost; thus from the surface of mercury at an angle of incidence (431), of 78° 5′, but 754 rays out of 1000 become reflected. When the reflector is diaphanous, as a glass plate, more light is reflected from the second than from the first surface, and this increases by coating the back with some resinous cement, or still better, metallic amalgam; the vividity of the reflection from the second surface then infinitely eclipsing that from the first. Thus, in the common looking-glass, the bright images seen in it, are reflections from the second or coated surface.

432. Any substance possessing some regular form and sufficiently polished to reflect light, is termed a *speculum* or *mirror*. These are made of various materials, as of polished metal, or of glass, covered at the back with an amalgam of tin. Mirrors are made in various forms; of which, the *plane*

consists of a level surface of polished metal or glass, the concave presents a hollow surface like the inside, and the convex a projecting superficies like the exterior of a watch-glass. Besides these, mirrors have been constructed in the form of certain conic sections, as the ellipse, hyperbola, and parabola.

433. Rays of light falling upon the surface of a plane mirror, as a looking-glass, always retain their original rectilinear direction after reflection (431).



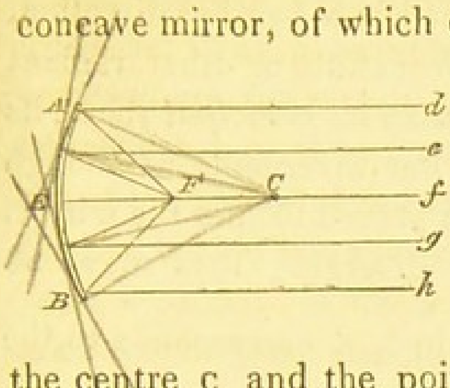
Let AB be the surface of a plane polished mirror, and CD be *parallel* rays incident upon its surface, they will be reflected in the direction *cd*, according to the laws already mentioned. *Diverging* rays proceeding from E will, after incidence, continue to diverge in the direction *eee*, and *converging* rays, as FFF, will continue to converge after being reflected from AB towards the point. In all these cases, as objects appear to the eye to be situate in the direction of the rays which eventually reach that organ, to spectators placed at *cd*, *eee*, and G, the rays CD, E, and FFF, will appear to have come from behind the mirror AB in the direction of the dotted lines C′D′, E′, and F′F′F′. In all these cases, the effect of reflection is merely to throw the apparent origin of the rays to the opposite side of the mirror, and to *invert* the direction of these incident beams; for, taking the case of parallel rays, the ray D*y*′ being the uppermost before reflection passes in the direction of *yd*, and becomes lower than *cx*, representing the course of the reflected ray C*x* which before reflection was below D*y*; and so on, of the other cases of diverging and converging light.

434. As all bodies become under certain circumstances the source of luminous undulations proceeding from every point of the object, and possessing a degree of rapidity corresponding to the colours of the substance; or, in conventional language, all bodies evolve rays of the same colours of themselves; it follows, that any object placed at CD (433), will appear to a spectator placed at *cd*, to be in the direction C′D′, as the rays evolved from the object will, after reflection on AB, proceed in the direction *xc*, *yd*, and consequently appear to the observer to have been given off from some object situated at C′D′, as far behind AB as CD is before it. This representation of the object so vividly presented to the idea is termed an *image*, and precisely resembles in tint and outline the real object to reflection from which it owes its origin.

435. When two plane mirrors (432), are placed parallel to each other, and any object be situate between them, a long and almost infinite series of images will be seen in each mirror, from the object and its image in one being reflected by the other, and so on, until these figures appear so remote as to be invisible. If the two reflecting surfaces be inclined towards each other at any angle, the images of any object placed between them will appear to lie in the circumference of a circle of which the mirrors represent the radii. This is the principle of the kaleidoscope invented by Sir David Brewster: in this elegant instrument, the images of the objects placed between the reflectors are seen most beautifully arranged when the latter form an angle, which is an even aliquot part of a circle. Thus, if the angle between the mirrors be 60°, the images of the object will appear arranged in a circle, and an hexagonal figure will be produced; for if the angle be a measure of 180, the number of images formed will be equal to 360 divided by that angle.

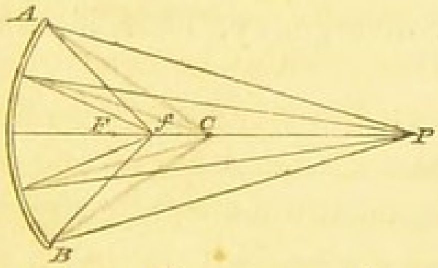
436. When parallel rays of light, as when emanating from a distant body (430), be incident upon a *concave* reflecting surface, they are reflected as if from a series of planes, tangents to that surface, and are made to converge. Thus if AB be a

concave mirror, of which C is the geometrical centre, and parallel rays, as *defgh*, be incident upon it, they will be reflected according to the general law of reflection (431), and consequently be made to converge towards a point F, situate midway between the centre C and the point E, F being consequently equal to half the radius of the concavity of the mirror.



It is obvious that all the luminous undulations producing the rays *defgh* will be reflected towards F, and, arriving there at the same instant, will cause any particles of ether there situated to be acted upon and agitated with an intensity corresponding to the united force (422) of all the undulations propagated from the reflecting surface; on which account all the light and heat belonging to the incident rays will become concentrated at F, and luminous and calorific effects of corresponding intensity will be excited on any body placed at that spot. This point is hence termed the *focus* or *fire-place* of the mirror AEB *for parallel rays;* the distance FE being termed the *principal focal distance, or length* of the mirror.

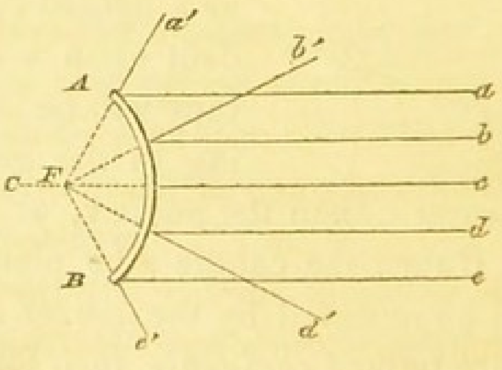
437. If *diverging* rays be incident upon a concave mirror, they will be conveyed to a focus which differs from the point F in the last figure, approaching the centre of the mirror's concavity. Thus, if rays diverging from a luminous source, as a lighted candle P, be incident upon a concave mirror, they will be reflected, according to the general law, to a focus *f* much nearer C than the point F, or focus for parallel rays (436). If then the candle P be placed at *f*, the luminous rays will be reflected by the mirror to a focus at P; hence P and *f* are termed *conjugate foci*, for either becomes the focus to a radiant point placed at the other. Whereas, in the case of parallel rays (436), if the source of light be



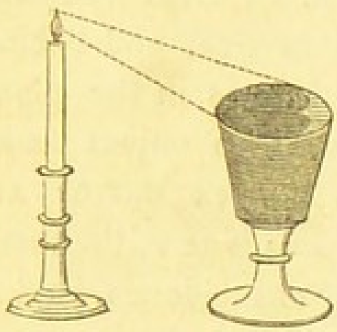
placed at F, the rays will be reflected in a parallel direction, and never meet at a focus. If the candle or other radiant point be placed nearer the mirror than *its principal focus*, its rays will be reflected, not parallel but divergent, as though they were evolved from some point placed behind the mirror. The conjugate focal distance for diverging rays may be found by the formula $\frac{d+r}{2d \times r}$ in which d corresponds to the distance of the source of light from the mirror, and r to the radius of curvature of the latter.

438. When converging rays are incident on a concave mirror, they will be reflected to a focus further from the centre of the mirror's concavity than the principal focus or F (436), the reverse consequently of diverging rays. These rays, falling on a mirror, appear to converge towards a point situated behind it, and their focus may be found by the following formula, in which c corresponds to the distance of the point of convergence from the mirror, d and r retaining their former values (437) $\frac{c \times r}{2d+r}$.

439. When luminous rays are incident upon convex mirrors, they are acted upon in a manner opposite to that which they were by concave reflecting surfaces; for whilst a concave reflector lessens the divergency, and increases the convergency of all incident rays, a convex one increases their divergency and diminishes their convergency. Thus, if parallel

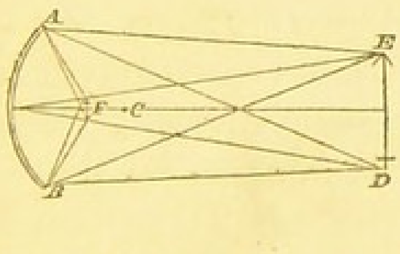


rays *abcde* be incident on the convex mirror AB, of which C is the centre of convexity, they will be reflected, according to the general law (431), in the direction $a'b'd'e'$, as if they proceeded from a point F placed behind the mirror, which thus becomes the *virtual, apparent,* or *negative* focus of the reflected rays. The *focal distance* F for parallel rays is one half of the radius of the convexity of the mirror, and always situated behind the mirror, whilst in *concave* reflectors it is before it (436). In the case of diverging rays, the focal distance will be less, and for converging beams greater than Y.



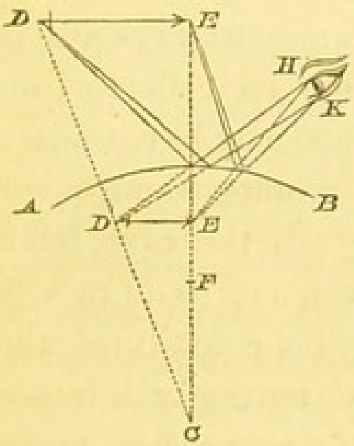
440. When luminous rays are incident upon a curved reflector, any point of its surface may be considered as an infinitely minute plane mirror (432), reflecting all the rays falling upon them. When a series of rays fall upon a surface thus constituted, they after reflection mutually intersect, and these points of intersection constitute a curved line, termed a *caustic.* To exhibit this caustic curve by reflection, nearly fill a glass tumbler with milk, or fit a circular piece of card into it about half an inch from the top, and, exposing the concavity of the glass to the sun or a candle, a brilliant double curve will be represented on the surface of the milk, or piece of paper.

441. Images are formed by spherical mirrors in the same manner as by plane ones, and differ from those produced by the latter instruments in being of a different size from the object.



Thus, if rays be supposed to emanate from a distant body, they will, on being incident on the concave mirror AB, of which C is the centre of concavity, be reflected to a focus at F, a little beyond the principal focus (436), and there paint an image of the object ED, diminished in size, and, from the altered relative position of the rays after reflection (433), inverted in direction. The image

F will be extremely vivid from its being virtually illuminated by all the luminous rays incident on the mirror. The magnitude of the image F will be found to bear the same relation to ED as the distance of F from the mirror does to that of the object from it. If an object be placed at F, its image will be painted on a screen placed at ED, diffused over a large space, and consequently magnified.



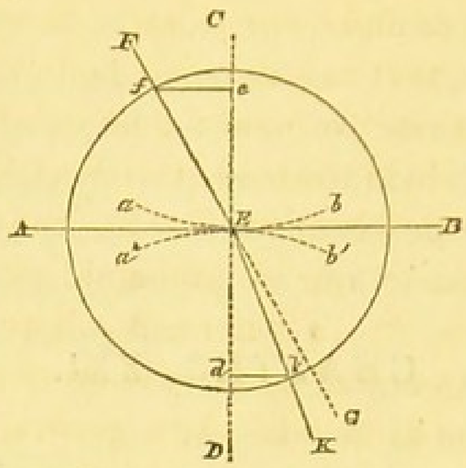
442. In the case of convex mirrors, the images are in an erect position, much diminished in size, and behind the reflecting surface as in the plane mirrors (432); for if an object DE be placed before a convex mirror AB, whose negative focus is at F, the luminous rays will, after incidence on AB, be reflected diverging; and being seen by a spectator at H, they will appear to him as proceeding from an object *de* behind the mirror, and considerably smaller than DE, of which it is merely a diminished image.

CHAPTER XXI.

UNPOLARIZED LIGHT. (DIOPTRICS.)

Law of Sines, 443. *Refraction from dense through rare Media*, 444. *Index of Refraction*, 445. *Refraction through two Media*, 446. *Limit to Refraction, internal Reflection*, 448-9. *Refraction through Parallel Surfaces*, 450—*through Prisms*, 451. *Lenses*, 452. *Refraction through Spheres*, 453-4—*through Convex Lenses*, 455. *Formulæ for Focal Lengths*, 456. *Refraction through Concave Lenses*, 457—*through Menisci and Concavo-convex Lenses*, 459. *Caustics by Refraction*, 460. *Formation of Images by Lenses*, 461-2. *Magnifying Power of Convex Lenses*, 463-4. *Spherical Aberration in Lenses*, 465—*in Mirrors*, 466.

443. So long as a ray of light traverses an uniform medium, it continues its path in a right line, which it also preserves when it is incident on a diaphanous substance, in a direction perpendicular to its surface. But if it be incident in an oblique direction, it becomes somewhat bent, or *refracted*, out of its original course: this bending, or *refraction*, not being constant for every substance, as the direction of reflection (431) is, but varies considerably in different forms of matter. Thus, let AB be the surface of a refracting medium, as water; draw CD perpendicular to it, and let FE be a ray incident on AB at E, a certain portion will be reflected (431*), the remainder entering the medium, and instead of following the direction EG, will be refracted or bent towards D in the direction EK. The line FE will, therefore, represent the incident, and EK the refracted ray; FEC will be the angle of incidence, and DEK the angle of refrac-



tion. Draw the lines *cf dk*; the former will be the sine of the angle FEC, and the latter that of the angle DEK, and will be to each other in a constant ratio for each refracting substance: the sine *dk* being to the sine *fc* as unity is to the refracting power of the medium, or in the case of water as 1 to 1·336; the latter being the *index of refraction* of the medium AB, and is found by dividing the sine *fc* by the sine of refraction *dk*. From this reasoning, we see that the incident and refracted rays must always be in the same plane, but on different sides of the perpendicular CED.

444. As the visibility of any two points is mutual, it follows that a ray of light, KE (443), passing from a refracting medium, ADB, as water, will, on reaching the surface AB of a rarer one, be refracted into the direction EF. In this case, as KE is the incident, and FE the refracted ray, the line *fc*, or sine of refraction, is greater than the line *dk*, or sine of incident, the reverse of the former case, and *fc* will be to *dk* as 1·336 is to 1. The index of refraction for a ray passing from a denser into a rarer medium, or, in this case, from water into a vacuum, may be found by dividing unity by the refracting index of the denser medium, or $\frac{1}{1\cdot336}$; it is, therefore, equal to the *reciprocal* of the refractive index of the water, or other dense medium.

445. The index of refraction, or refractive power of a medium, varies considerably, being for chromate of lead 2·974, and for air 1·000276, between which limits every in-

termediate degree of difference exists. It was suggested, by Sir Isaac Newton, that inflammable bodies in general possessed a higher refractive power than other substances; on which account he made the bold statement, that the diamond, whose refractive index is about 2·439, consisted of a combustible substance ("qui ut probabile est, substantia est unctuosa coagulata"*); a statement whose correctness has been amply demonstrated by the discovery of the true chemical nature of the diamond. As a general law, the greater the specific gravity of the body, the more it refracts light passing through it; and the only exception is found in the case, pointed out by Newton, of inflammable bodies; and if allowance be made for the generally lower specific gravities of this class of substances, they will be found to possess a greater *absolute* refracting power than any other bodies. In the following table the index of refraction of several substances, when a ray is incident upon them from a vacuum, is contrasted with their absolute refracting powers:

Name.	Refracting Index.	Absolute Refract. Power.	Name.	Refracting Index.	Absolute Refract. Power.
Vacuum . . .	1.000000	0.	Alum	1.457	0.6570
Hydrogen . .	1.000138	3.0953	Oil Olives . .	1.470	1.2607
Oxygen . . .	1.000272	0.3799	Oil Turpentine .	1.475	1.351
Common Air .	1.000294	0.4528	Castor Oil . .	1.490	1.148
Nitrogen . . .	1.000300	0.4734	Oil of Cloves .	1.535	1.309
Ammonia . .	1.000385	0.4734	Crown Glass. .	1.525-1.534	0.526
Carbonic Acid .	1.000449	0.4537	Plate Glass . .	1.514-1.542	?
Chlorine . . .	1.000772	0.4813	Amber . . .	1.547	1.3654
Tabasheer . .	1.111	?	Quartz . . .	1.548	0.5415
Fluids in Topaz.	1.294-1.31	?	Flint Glass . .	1.585-1.60	0.7986
Ice	1.309	?	Oil of Cassia .	1.641	1.7634
Water . . .	1.336	0.7845	Sulphuret of Carbon . .	1.768	1.4200
Ether	1.358	2.56			
Alcohol . . .	1.372	1.0121	Sapphire . . .	1.794	0.5556
Hydrochloric Acid . .	1.410	0.5514	Garnet . . .	1.815	0.5423
			Zircon . . .	1.961	0.6054
Nitric Acid . .	1.410	0.624	Sulphur . . .	2.148	2.2000
Sulphuric Acid .	1.434	0.6124	Phosphorus . .	2.224	2.8857
Fluor-Spar . .	1.434	0.3414	Diamond . . .	2.439	1.4566

* Newton. Optice, sive de reflexionibus, &c., lucis, lib. ii. pars. 3. Lat. red. S. Clarke, London, 1719.

On looking at this table, it will be found that the absolute refractive power of hydrogen exceeds that of all other bodies, when allowance is made for its low specific gravity. These absolute refractive powers are calculated on the supposition of the ultimate particles of bodies being equally heavy, by dividing the excess of the square of the index of refraction above unity, by the specific gravity of the substance.*

446. When the refracting action of any medium, on a ray entering it from a vacuum, is required, the above table will suffice; but when the direction of a ray passing from one medium to another is sought for, we must divide the index of refraction of the second medium by that of the first, and the quotient will give the ratio of the sine of refraction to that of incidence from one body to the other. Thus, if the index of refraction for a ray passing from water into plate-glass were required, the index of refraction of the former being 1·336, and of the latter 1·542, we have only to divide the latter by the former number, or $\frac{1 \cdot 542}{1 \cdot 336} = 1 \cdot 154$, the required index.

447. When a ray is incident on a refracting surface, bounded by curved lines, the same law obtains as when incident on a plane. For if AB (443) were replaced by a concave or convex surface, as *ab* *a'b'*, the ray FE will follow the same course, as if it impinged on a plane, a tangent to the curve at the point of incidence.

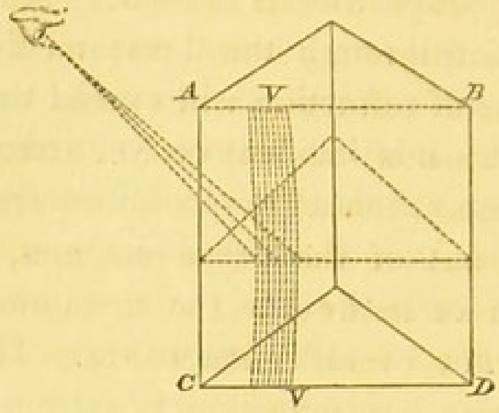
448. From an inspection of the diagram (443), ABC being a rarer and ABD a denser medium, we see that the sine *fc* of the incident is always greater than the sine *dk* of the refracted rays; and if the ray FE were incident at so great an obliquity that its sine would nearly correspond to radius, and, consequently, that the luminous ray could only graze the surface of the medium ABD, still a considerable portion of the light would really enter and be refracted, as the sine of refraction in a dense medium is invariably less than the sine of incidence. The

* Newton. Optice, sive de reflexionibus, &c., lucis, lib. ii., prop. 10.

converse of this proposition is extremely remarkable; for if KE be a ray passing through the dense medium into a rare one ACB, the sine of refraction will exceed that of incidence (443); and when KE is incident on AB, at such an obliquity that the sine of the refracted ray would correspond to radius, it ceases to pass out of the dense medium, and is *reflected* from the surface AB back into the medium ABD, according to the ordinary law of reflection (431). This sudden conversion of refraction into reflection is extremely remarkable, and affords the only instance of *total* reflection with which we are acquainted; for if the ray be incident in a dense medium on the surface of a rarer one at a sufficient obliquity, it is totally reflected, no light being lost, except from a few undulations being checked by the medium itself. The angle at and within which this *internal reflection* occurs is termed *the limiting angle* between refraction and reflection. This *limiting angle* may be found by dividing unity by the index of refraction of the substance; and on looking for the quotient in a table of natural sines, the angle corresponding to it is the limiting angle. Thus, a ray cannot pass from water into a vacuum, if the angle of incidence exceed 43°·27′ for $\frac{1}{1\cdot 336}$ = sine of that angle; nor can a ray pass from flint glass into vacuum, if the angle exceed 38°·41′ for $\frac{1}{1\cdot 60}$ =6250, the sine of that angle. The brilliancy of the light thus reflected far exceeds that reflected from the best metallic mirrors. This may be readily shown by nearly filling a glass with water, and holding it up, so that the surface of the fluid may be seen from beneath: it will appear like a sheet of burnished silver, from the perfect reflection of the incident light, and no object held above it will be visible if the position of the eye be within the *limiting* angle.

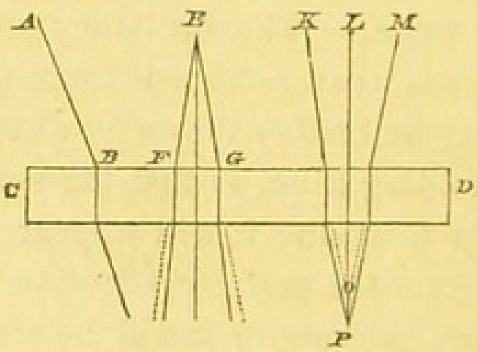
449. The transition from positive to total reflection may be beautifully seen in an experiment described by Newton.* Hold an equi-angular prism, in the position shown in the

* Optice, *supra citat.* Lib. ii., exp. 16., p. 159.



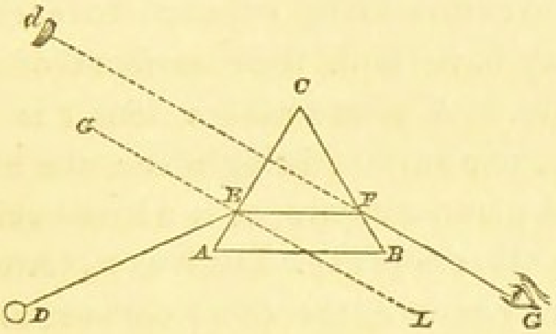
figure, before an open window, in such a manner, that a line drawn from the eye may describe an angle of about 40° with the base of the prism. The base ABCD will appear to be bisected by a curved iris, VV, of a bluish violet colour, the space between VVAC appearing of a sombre hue, in which reflection is extremely imperfect; but beyond VV, including the space VBVD, the whole will appear shining with a metallic splendour, the clouds and surrounding objects being depicted upon it with great brilliancy. The iris VV thus divides the space between partial and total reflection.

450. If a ray of light be incident upon the surface of a refracting medium, bounded by plane parallel sides, as a plate of glass, it will undergo no change of direction, if it



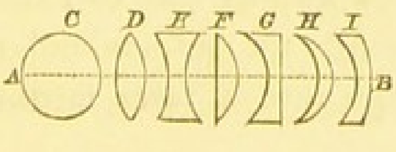
describe a perpendicular to the refracting surface; in any other direction it will be refracted according to the laws already detailed. Thus, if AB be incident on a medium, as a pane of glass, CD, it will undergo refraction, and escape on the opposite side, in a direction parallel to the incident ray. If diverging rays, as EFG, be incident, they will, after refraction, emerge from CD parallel to their former direction, their divergence having become diminished; and if converging rays, as KLM, be incident on CD, and converging to O, they will, after converging from the medium, really converge at P.

451. Prisms are made for optical purposes, with their sides at various angles of inclination. ABC represents one whose sides are inclined to each other at an angle of 60°; CA CB



are termed the refracting sides, and AB the base of the prism. If a ray of light, DE, be incident on the side CA, it will be refracted towards its base if the prism be denser, and towards its apex if rarer, than the surrounding medium. Let the prism be of glass, and draw GEL perpendicular to AC; the ray DE, on entering the prism, will be refracted towards its base, and consequently towards the perpendicular GEL in such a manner, that the sine of the angle GED will bear the same relation to the sine of EFL that the index of refraction of the glass prism does to that of the surrounding medium or air. Hence, in viewing objects through a prism, they always appear to be higher or lower than they really are; for, if an object be placed at D, it will appear to a person stationed at L to be at *d*, because the ray FG, if produced, will reach *d*, *and objects always appear to be situated in the direction of the rays which eventually reach the eye* (433).

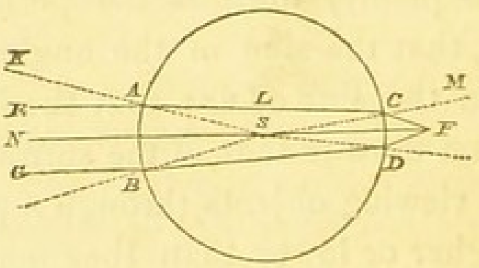
452. Lenses are for optical purposes constructed of glass



and certain transparent minerals of various forms. Sections of the principal kinds of lenses are shown in the preceding figure; and, if these be supposed to revolve round the axis AB, each will describe the particular lens of which it is the section.

The *spherical lens* is a simple sphere of glass, C; the *double convex* D is bounded by two convex surfaces, concave towards each other; the *double concave* E has both its surfaces concave, their convexities being opposed to each other; these two lenses may have both their surfaces of unequal, or of equal curvature. A *plano-convex* lens F is merely half a double convex, one surface being plane, the other curved, as in the latter. A plano-concave, G, is a lens having one surface plane and the other concave. The lens H, termed a *meniscus*, has one surface concave, the other convex, and these curves meet if continued; whilst the concavo-convex lens I has similar surfaces, but they do not meet if produced, as the convex surface has a lesser curvature than the concave side.

453. The course of a refracted ray through a spherical lens may be readily understood; for let ABCD be a sphere of flint glass of a refractive index of 1·60 (445), and let the



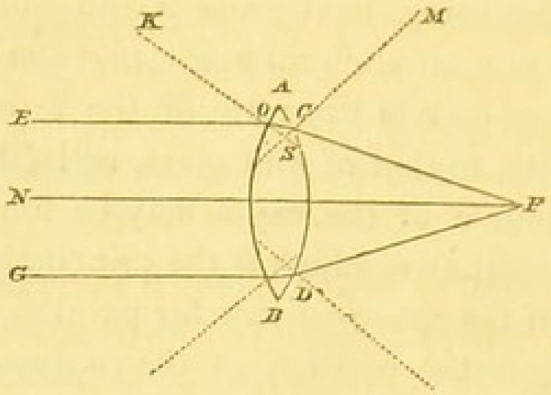
parallel rays ENG be incident upon it—the ray N, being incident perpendicular to the spherical surface, will pass through without refraction (443). To find the course of the ray E, draw the perpendicular KAS, and produce the line E to C with such an obliquity that the sine of the angle ALS may be to the sine of the angle KAE as 1 is to 1·60; the ray ALC becomes thus bent towards the perpendicular KS. On reaching C, the ray will emerge into a rarer medium, and will again suffer refraction, being bent *from* a line MCS perpendicular to the surface at C, at such an angle that the sine of LCS will be to the sine of CMF in the ratio of the refractive index of air, or 1·000294, to that of flint glass, or 1·60. By a similar process, the course of the ray G may be found. The three rays will thus meet at F, which is the principal *focus*, or *focal length* (436) of the spherical lens for parallel rays.

On referring to the position of the *conjugate foci* of concave mirrors (437), it will be readily seen that, if diverging rays be incident on the sphere of glass, their focal distance will be beyond F; and if converging rays be incident, their focus will be at some point nearer the sphere than the focus for parallel rays, or F.

454. The course of the refracted rays, and, consequently, the position of the focus F, will vary according to the refractive power of the substance of which the lens is constructed. Thus, Sir David Brewster* has shown, that in a sphere of Tabasheer, whose refractive index is 1·11145, the focal distance for parallel rays will be four feet from the lens; in one of glass of a refractive index of 1·5, it will be but half an inch; and in one of zircon, whose refractive index is 2·0, it will coincide with the surface of the sphere. To find the focal distance of a sphere from its centre, divide the index of refraction of the material of which it is constructed, by twice its excess above unity, and the quotient will be the distance expressed in radii of the sphere. Thus, if the radius of a spherical lens be one inch, and its refractive index 1·6, we shall have 1·33 inches as the distance of the focus from the centre of the sphere; and by subtracting the radius, or one inch, we obtain the distance of F from the surface.

455. The course of a ray through a double convex lens, may be found in the same manner as that already explained in the case of a sphere (453). Let the lens AB be of the same material as the sphere, and ENG three rays entering it; N

* Treatise on Optics, p. 37. London, 1831.



will pass on and emerge without refraction. The ray, E, will, on entering the lens, be refracted *towards* the perpendicular KOS; and on emerging from C into a rarer medium, the air be again refracted, but in a contrary direction, or *from* the line SCM, drawn perpendicular to the point of emergence. By a similar process, the course of the ray G may be ascertained; ENG will thus be found to meet at F, which is the principal focus of the lens. The amount of refraction experienced by the rays on entering and emerging from the lens, may be found precisely as in the case of refraction through a sphere (453). Taking the ray E as an example: on entering the lens it will be refracted, so that the sine of the angle KOE will be to the sine of OCS nearly as 1·60 to 1; and on emerging from the lens at C, the sine of CSO will be to the sine of CMF as 0·6252 to 1·0 (444).

If the rays incident on the lens AB be *converging*, the focus will be nearer the surface of the lens than F; but if *diverging*, their focus will fall beyond that for parallel rays. The course of refracted rays, through plano-convex lenses, as well as through convex lenses of unequal curvature, may be found by the process already described for double convex glasses of equal curvature.

456. The focal length F (455) of convex lenses of all kinds, may be found by the following formulæ:

Radius of curvature of one surface $= r$.
. . . of the other $= r'$
Distance of the source of light $= d$.

Distance of the point of convergence
of the rays from the lens $= d'$.
Thickness of the lens . . t.

* For *Parallel rays.*

(A.) Double convex lenses of equal curvature . $F = r$.

(B.) Double convex lenses of unequal curvature

$$F = \frac{2\,(r \times r'}{r + r'.}$$

(C.) Plano-convex lenses:

1, plane surface exposed to the rays . $F = 2\,r$.

2, convex surface exposed to the rays . $F = 2\,r - \frac{2\,t}{3.}$

** *Diverging rays.*

(D.) Unequally double convex lenses $F = \frac{2\,(r \times r') \times d}{\{(r + r') \times d\} - 2(r \times r')}$.

(E.) Equally double convex lenses . $F = \frac{d \times r}{d - r.}$

(F.) Plano-convex lenses . . $F = \frac{d \times r}{d - 2r.}$

*** *Converging rays.*

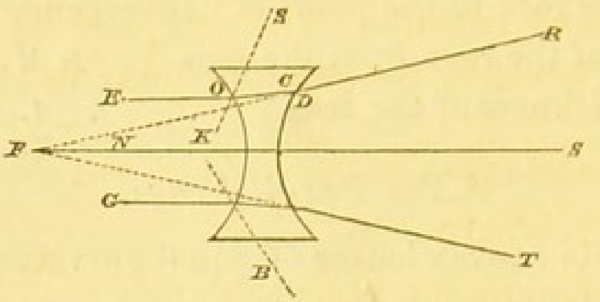
(G.) Equally double convex lens . $F = \frac{d' \times r}{d' + r.}$

(H.) Double convex lenses of unequal curvature

$$F = \frac{2\,(r \times r') \times d'}{\{(r + r') \times d'\} + 2\,(r \times r.}$$

(I.) Plano-convex lenses . . $F = \frac{2\,(d' \times r)}{d' - 2\,r.}$

457. To find the course of rays incident on a double concave lens, as AB, let ENG be as before, the rays of which N, will pass through without refraction. E, on reaching O, will enter the glass, and become bent *towards* KS, a line perpen-



dicular to the point of incidence, in such a manner, that the sine of the angle EOK will be to the sine of SOC, in the ratio of the index of refraction of the glass to that of the air, as in the case of the convex lens (455). On reaching D, the ray EOC will emerge and undergo a second refraction, by which its divergence will be increased. The course of the ray G may be found in a similar manner. Thus, the parallel rays ENG are made to diverge by refraction through a concave lens, instead of converging, as in a convex glass. The emergent rays RST will diverge in the same manner as they would if they had proceeded from a radiant point at F, as shown by the dotted lines FT, FR; this point is the principal focus of the lens, and is a *virtual, apparent*, or *negative* focus, as in the case of reflection from convex mirrors (439).

The course of refracted rays through plano-concave and double-concave lenses, of unequal curvature, may be found by a similar process. From an inspection of the last diagram, it is clear, that if the incident rays on a concave refracting surface be converging, their negative focus will be nearer the lens; and if diverging, further from it than the principal focus F.

458. The negative focal lengths, for parallel rays, of all the varieties of concave lenses, may be found by means of the formulæ already given for convex glasses. Their foci for converging rays may be found by the formulæ for diverging rays with convex lenses (456, DEF), and vice versâ.

459. The action of menisci (452, H) and concavo-convex lenses on rays of light, is precisely the same as that of convex and concave lenses of the same focal length; the foci in

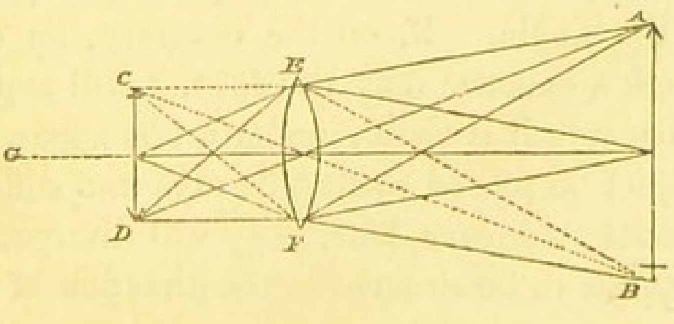
the former being real or positive, whilst in the latter they are virtual and negative. In both varieties of lenses, the foci may be found by the following formulæ:

(A.) For parallel rays . . $F = \frac{2(r \times r')}{r - r'}.$

(B.) For diverging or converging rays $F = \frac{(r \times r') \times 2d}{\{(r - r') \times d\} + 2(r \times r')}.$

460. Caustic curves are formed by the intersection of luminous rays during refraction, in the same manner as by reflection (440). They may be seen by holding a glass sphere near a candle, and allowing the refracted rays to fall, after passing through the sphere on a sheet of paper held nearly parallel to its axis; a luminous figure, bounded by two sharp curves, will be observed, meeting at a point corresponding to the focus of the lens. These curves may be more distinctly seen by covering a cylindrical glass vessel, as a common tumbler, with black paper to about an inch of the top; pour water into this vessel, until it rises half an inch above the level of the paper. Cut a piece of white card, so that when placed at the level of the black paper, and perpendicular to the axis of the vessel, it may half surround the glass; then hold the latter up to the sun, or before a candle, with the card away from the source of light. The luminous rays passing through the water will be refracted to a focus on the card; and a triangular luminous figure, bounded by caustic curves, will be depicted upon it.

461. Images are formed by lenses in the same manner as they are by mirrors (441). Let AB be an object situated at a

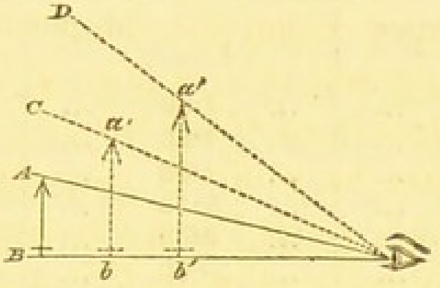


considerable distance; the rays propagated from it will, on reaching the convex lens, EF, suffer refraction, and after emergence will paint on a screen, placed near its principal focus (456), the image CD of the object, but in an inverted position, in consequence of the crossing of the rays. If the screen be removed, and a piece of ground glass be placed at CD, the eye placed behind it, as at G, will see the image very distinctly; then let the glass be removed, and if the eye has been placed within the limits of distinct vision, a picture of the object will be seen painted in the air, a little beyond the principal focus of the lens.

462. If the object be within a moderate distance of the lens, its image will be formed on a screen as before; and will be visible most distinctly when the object and the screen are each placed in the conjugate foci (437) of the lens. If the object be still nearer, and it be viewed through one of the modifications of the convex lens, it will appear larger, and if through a concave lens, smaller than it really is. This curious property of lenses entirely depends upon the apparent angle under which the object is viewed. Taking first the case of the double convex lens, as AB (455), let the rays ENG be supposed to pass from an object placed near it, and the eye be placed between the lens and its focus F: under these circumstances, the object will appear to be larger than it really is; for if the rays FC, FD be produced, they will diverge at a very considerable angle, and, as bodies always appear to be placed in the direction pursued by the rays, which ultimately reach the eye (451), the rays FC FD will appear to have passed from the object in right lines, and the object will appear to the eye to be sufficiently large to fill up the whole opening of the angle. If, on the contrary, an object be viewed through a concave lens AB (457), it will appear to be diminished, because it is visible under a less apparent angle. For if an object be placed so that its rays ENG suffer refraction in the double concave lens, they will diverge, and the object will appear to be situated in the direction of the right

lines RF, TF, and included in the angle of convergence of those rays.

463. The manner in which the eye judges of the size of an object, according to the apparent angle under which it is visible, may be readily shown; for if the eye placed at E views an object AB placed at such a distance that the right lines AA, BB, connecting it to the eye, may form an angle



of 20°, it will appear of a certain magnitude. Approach AB to the position *ab*, it is evident that it will appear under a greater apparent angle than before, as a line C, passing through it to the eye, will, with B, describe an angle of 40°, and, judging of its size from this angle, it will appear to be twice as large as when at AB. Bring *ab* to the position *a'b'*, now it will appear to be three times as large as it was when at AB; for D forms with B an angle of 60° and $60 \div 20 = 3$.

Thus, it is evident, that the longer the focal distance (456) of a lens, the lesser apparent angle is it seen under, and, *cæteris paribus*, the smaller it appears; whilst the shorter the focal length, the greater the apparent visual angle of the object, and the larger it appears. In the above account of the refraction of rays, and magnifying or diminishing power of lenses, it must be recollected, that the lenses under consideration are supposed to be denser, or of greater refractive power, than the medium in which they are immersed. For if they be rarer, or of less refractive power, then concave lenses will converge rays and magnify objects, whilst convex ones will diverge rays and diminish objects.

464. The magnifying power of a lens may be determined

by the limit of distinct vision for minute objects, which is generally about five inches, divided by the focal length of the lens. This refers to its linear magnifying power, and only to the number of times it is magnified in length; its superficial power being obtained by squaring its linear, and represents the number of times its whole surface appears to be magnified.

Focal length of lenses in inches.		Magnifying power. Linear.		Superficial.
5	...	... 1·00	...	... 1
4	...	... 1·25	...	... 1·5625
3	...	... 1·66	...	... 2·7556
2	...	... 2·50	...	... 6·25
1	...	... 5·00	...	... 25·
$\frac{1}{10}$	...	... 50·00	...	... 250·

465. On referring to the diagram of the course of rays refracted by a convex lens (461), it will be seen, that the rays passing nearest the axis of the lens will be refracted to a focus at a greater distance from the glass, than those which pass nearer the circumference. On holding a screen of ground-glass near the focus of the central rays, a picture of an object on the other side will be seen very vivid in its centre, but less distinctly defined at the edges; on gradually withdrawing the screen, the marginal portion of the picture will become more vivid as the centre loses its distinctness. Hence, it is obvious, that no object can be seen, with perfect distinctness, in every part, through a convex lens, at the same moment, in consequence of this *spherical aberration*, as it is termed. In a plano-convex lens, with its convex side towards the object, this *aberration* amounts to 1·17 of the thickness of the lens; but when the flat side is towards the object, this aberration amounts to 4·5. In a double convex lens, with equal radii of curvature, the aberration is 1·67 of its thickness.

These rules apply equally to the varieties of concave lenses.

To remedy this aberration, elliptic and hyperbolic lenses have been proposed, but the difficulty of constructing them has hitherto proved an effectual bar to their general adoption.

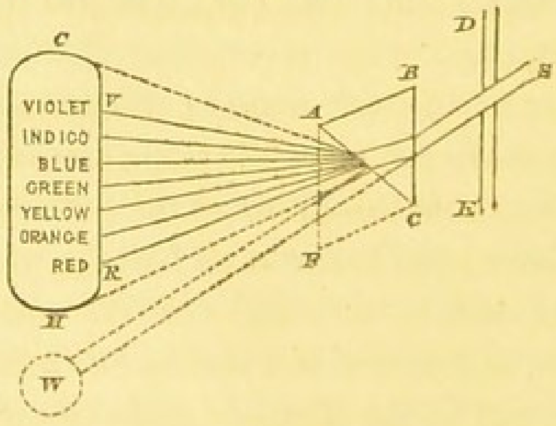
By means of the meniscus, spherical aberration may be nearly completely removed, if the convex surface be turned towards the object; providing the distance of the points of convergence or divergence from the centre of the first surface, be to its radius as the index of refraction of the lens, is to unity. By combinations of lenses, the spherical aberration may be reduced to an insensible quantity; these are fully described in all works on practical optics.

466. Spherical aberration is also observed in concave mirrors, and, as in lenses, interfere considerably with the distinctness of the image. This source of error in experiments in which mirrors are employed, can only be effectually prevented by giving to the reflecting surface such a figure, as will enable it to reflect all the rays incident upon it to one focus. The parabola and ellipse possess this property, and nothing but the mechanical difficulty of constructing mirrors of these figures prevents their being employed instead of spherical mirrors.

CHAPTER XXII.

UNPOLARIZED LIGHT. (CHROMATIC PHENOMENA.)

467. If a number of luminous undulations be propagated through a prism, so that rays may leave it at the same angle with regard to the sides as they entered it, their rapidity be-



comes remarkably affected. The light not only appears to emerge as if it had been refracted towards the thick part of the prism (451), but it becomes resolved into a set of undulations varying in amplitude and rapidity; and these are rendered obvious after leaving the prism, by their producing the phenomena of colours when received on a white screen. Thus, through a hole in the shutter DE, let a ray of light SW, be transmitted, interpose a glass prism ABC, so that the ray may be refracted through it, and a long *spectrum* composed of bands of different colours insensibly passing into each other will appear on a screen CH placed at a proper distance. The upper coloured part of this *spectrum* will be deep violet, and the lowest a dark red. This remarkable experiment was first performed by Newton,* and is usually termed the prismatic decomposition of light—white light being considered as being composed of seven distinct, simple, and *homogeneous* colours. But it is almost impossible to point out in the spectrum, as it is termed, any distinct line of demarcation between adjacent tints: for as the violet, indigo, and blue melt into each other, the latter colour and green can scarcely be distinguished at their point of junction, and the yellow, orange, and red are still more closely united. So that, although Sir Isaac Newton adopted seven, as the number of primary colours, it is better with Euler to consider that, whilst the extreme violet is produced by the greatest number of undulations, and the red by the smallest number, in a given time, there exists between these extremes every degree of variation in the rapidity of undulatory movement, and consequently infinite varieties of tints and colours.

468. Aided by a friend, whose perception of colours he considered to be very delicate, Sir Isaac measured with as much accuracy as possible the limits of the different coloured bands of the spectrum; he found their lengths, reckoning from the violet to the red to be nearly in the ratio of the numbers $\frac{8}{9}$, $\frac{5}{6}$, $\frac{3}{4}$, $\frac{2}{3}$, $\frac{3}{5}$, $\frac{9}{16}$, $\frac{1}{2}$, a series nearly corresponding to the intervals of sound in the diatonic scale or gamut (196). The

* Optice, lib. i., part 2, prop. 3, exp. 7.

following are the linear measures of the spectrum made by Newton (who unfortunately did not describe the kind of glass of which his prism was constructed) (478), compared with similar measures made by Fraunhofer with a prism of flint-glass,— each philosopher dividing the entire length of the spectrum into 360 equal parts:

	Red.	Orange.	Yellow.	Green.	Blue.	Indigo.	Violet.
Newton . .	45	27	40	60	60	48	80
Fraunhofer .	56	27	27	46	48	47	109

469. As in the experiment above detailed (467), the violet rays undergo the greatest, and the red the smallest amount of deviation from the original direction of the ray SW; the former are termed the most, and the latter the least refrangible rays. When prisms of crown and flint-glass are used, the following are the indices of refraction (443) of the different coloured rays:

	Red.	Orange.	Yellow.	Green.	Blue.	Indigo.	Violet.
Crown-glass	1·5258	1·5268	1·5296	1·5330	1·5360	1·5417	1·5466
Flint-glass .	1·6277	1·6297	1·6350	1·6420	1·6483	1·6603	1·6711

470. If a second prism AFC of precisely the same kind be applied to the first ABC, as shown in the figure (467), the colours will vanish from the screen; the undulations will be reduced to an uniform velocity; and white light will be produced. This is termed *the recomposition of white light;* and as ABCF represents the section of a parallelogram, it is evident that resolution and recomposition of the luminous undulations ensue whenever they are propagated through a plate of glass, which may be considered as being made up of two very

acute-angled prisms applied to each other so that their apices and bases coincide.

The recombination of the coloured rays may be also shown by holding a convex lens between the prism and the screen, which, if sufficiently near the former, will bring all the rays to a focus, and reproduce white light.

471. From a set of accurate admeasurements made by Newton, the following table,* showing the lengths and rapidity of undulations producing the principal coloured rays of the spectrum, has been constructed :

Coloured Rays.	Length of luminous waves in parts of an inch.	Number of undulations in an inch.	Number of undulations in a second.
Extreme Red .	0·0000266	37640	458 mils. of mils.
Red . .	0·0000256	39180	477 ,, ,,
Intermediate .	0·0000246	40720	495 ,, ,,
Orange .	0·0000240	41610	506 ,, ,,
Intermediate .	0·0000235	42510	517 ,, ,,
Yellow .	0·0000227	44000	535 ,, ,,
Intermediate .	0·0000219	45600	555 ,, ,,
Green . .	0·0000211	47460	577 ,, ,,
Intermediate .	0·0000203	49320	600 ,, ,,
Blue .	0·0000196	51110	622 ,, ,,
Intermediate .	0·0000189	52910	644 ,, ,,
Indigo .	0·0000185	54070	658 ,, ,,
Intermediate .	0·0000181	55240	672 ,, ,,
Violet .	0·0000174	57490	699 ,, ,,
Extreme Violet	0·0000167	59750	727 ,, ,,

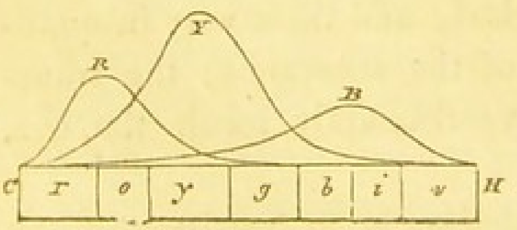
472. The seven colours of the solar spectrum are generally regarded as *simple*, because they cannot be separated into others by a second refraction through a prism, in which they differ from the tinted light obtained by passing the sun's beams through coloured glasses. When light passes through even the most transparent medium, as water or glass, some of its undulations become checked, and these vary in quantity according to the opacity of the substance; the transmitted undulations, whose rays ultimately reach the eye,

* Treatise on Light, in Encyclop. Metrop., by Sir John Herschel, 575.

communicate the sensation of that colour, which is produced by the undulations of *white* light *minus* those which have been checked or absorbed whilst passing through the given medium. Thus, on holding a piece of smalt blue glass between the eye and the light, the transmitted rays will be of a fine blue colour, and consist of a mixture of all those undulations which have not been checked by the glass; and if decomposed by the prism, will exhibit the usual *spectrum* (467), deficient only in those rays which were absorbed by the blue glass.

473. The rays thus absorbed by the blue glass are the red, with some of the blue. On examining the solar spectrum through such a piece of glass, which is best done by placing it before a prism, through which the observer is regarding a hole in the window-shutter, Sir David Brewster found that the greater part of the red and orange rays disappeared. The yellow band appeared greatly increased in breadth, encroaching on the spaces formerly covered by the orange on one side, and the green on the other. Hence, the coloured glass had absorbed those rays which, when mixed with the yellow, constitute orange and green, and consequently the green of the spectrum becomes decomposed into blue and yellow, and the orange into yellow and red. This has been by Sir David termed the simplification of the spectrum, by absorption and greatly corroborates the views of those philosophers who have argued for the existence of but three *primary* colours, as red, yellow, and blue.

474. The solar spectrum may therefore be regarded as composed of three spectra of equal lengths overlapping each other, the red having its greatest intensity in the middle of the red space; the yellow in the middle of the band of that colour, and the maximum of the blue between the band of that colour and the indigo. Sir David has exhibited by means of three curves the intensities of tint of the three



spectra, which he conceives to constitute the solar spectrum. Thus, if CH represent this spectrum (467), the red curve R commences abruptly at C, and gradually declines to H; the yellow one Y commences less abruptly; and the blue one B begins with a very gradual curve—the heights of the securves, or lengths of their ordinates, represent the intensities of the tints of these *primary spectra* in every part of CH.

Placing R for the primary red, B for the primary blue, and Y for the primary yellow rays, the following will be a view of the proportions in which these rays exist in the spectrum, and in white light:

Colour.	White.	Red.	Orange.	Yellow.	Green.	Blue.	Indigo.	Violet.
Proportion of primary rays.	20R+30Y+50B	8 R	7 R + 7 Y	8 Y	10 Y + 10 B	6 Y + 12 B	12 B	16 B +5 R

475. Media of various colours absorb different primary rays, by checking the undulations producing them; thus, the piece of blue glass already referred to (472), checked or absorbed the red, andpart of the blue; some pieces of red glass, or a combination of blue and red, absorb every ray except the homogeneous red. A solution of the ammonical-sulphate of copper transmits the violet, but checks all other undulations; whilst the ammoniacal-oxalate of nickel checks the violet, and transmits the blue and red. This remarkable absorptive power of different substances becomes curiously modified by heat, as shown by the tints assumed by various substances at different temperatures; thus, the periodide of mercury turns yellow, the binoxide of mercury black, and the salts of cobalt blue, on being heated.

476. On examining the solar spectrum (467), the green rays are observed to be placed very nearly in the centre, and are hence frequently termed the *mean* or *medium rays*

of the spectrum. If, instead of using the prism referred to, (467), one of the same kind of glass, but of greater refracting angle, be employed, the length of the spectrum, or distance of the mean rays from the extremities, will be increased; and diminished, if the refracting angle of the prism be lessened. But when the spectra produced by two prisms, one of flint, and the other of crown-glass of equal angles, be examined, that produced by the latter will be found to be shorter than that by the former; hence flint-glass is said to have a greater *dispersive power* than crown-glass, because it spreads or disperses the spectrum over a greater extent of space than the other kind of glass. A thin hollow prism of glass filled with oil of cassia, produces a spectrum of twice the length of one produced by a prism of solid glass, on account of the great dispersive power of that fluid.

If the prism (467) ABC be of flint-glass, and one of crown-glass AFC be applied to it, the spectrum will disappear, and the spot of light W will be reproduced, not colourless as when the prisms were of the same kind of glass (470), but tinted on one side with purple, and on the other with green light. This arises from the unequal lengths of the spectra produced by the prisms of different kinds of glass, and consequent different dispersive power, which prevents their (so to speak) completely neutralizing each other's effects.

477. The dispersive power of a substance is not proportional to its index of refraction, and may be calculated by dividing the differences of the indices of refraction for the red and violet rays, by the excess above unity of the index of refraction of the mean rays. Thus, the dispersive power of crown-glass is 0·03902 for 1·5466 — 1·5258 = ·0202 (469), and $\frac{\cdot 02080}{\cdot 5330} = 0{\cdot}03902$. The following table represents the dispersive power of a few substances, from the experiments of Sir D. Brewster:

Name.	Dispersive power.	Name.	Dispersive power.
Oil of Cassia .	0·139	Oil of Turpentine	0·042
Phosphorus .	0·128	Amber . .	0·041
Sulphuret Carbon	0·115	Diamond . .	0·038
Oil of Cloves .	0·062	Ether . .	0·037
Oil of Sassafras	0·060	Castor Oil .	0·036
Rock Salt .	0·053	Water . .	0·035
Oil of Thyme .	0·050	Plate-glass .	0·032
Oil of Carraway	0·049	Sulphuric Acid .	0·031
Oil of Juniper .	0·047	Alcohol . .	0·029
Flint-glass .	0·048	Rock Crystal .	0·026

478. Not only are the total lengths of the spectra altered by the substitution of prisms of different dispersive powers, but the spaces occupied by the coloured bands are not proportional to the altered length of the whole spectrum. This curious effect is termed the *irrationality* of the spectral dispersion, and is remarkably well shown by using two prisms, one of oil of cassia (476), the other of sulphuric acid. If the spectra produced be of the same length, the most refrangible colours, or those caused by the most rapid undulations (471), as the violet, indigo, and blue, will be found to occupy a much larger portion of the entire spectrum in the former than in the latter; the reverse being the case with the least refrangible rays, as red, orange, and yellow.

479. If the solar rays, admitted through a very narrow slit in a plate of metal, be examined through a prism, a long spectrum traversed by numerous dark lines will become visible; and if a bottle containing nitrous acid gas be interposed between the spectrum and the light, those lines will increase

so much, that the whole will present the appearance of a striped carpet.*

These lines were first observed by Dr. Wollaston, and have since been carefully studied by Fraunhofer, Brewster, and others. None of these lines exactly correspond to the boundaries of the coloured bands, and they appear for the same kind of light to be perfectly constant. About a thousand of them have been counted by Sir D. Brewster. Several of these lines have been selected by Fraunhofer, on account of their distinctness, and the facility with which they are discovered. These lines are known by the letters BCDEFGH: of these B lies in the red band near its extremity, C further advanced in the red, D is a strong double line in the orange space, very readily distinguished, E in the green, F in the blue, G in the indigo, and H in the violet spaces. There are besides, three very remarkable lines in the green band between E and F.

480. All these dark lines arise in all probability from certain undulations becoming checked or absorbed (473) during the passage of the light to our earth; those above referred to are constant only for the light derived directly or indirectly from the sun; for almost every fixed star has its own system of lines. The line D, indicating the place of a deficient ray, appears to be very constant in the planets, and in many of the fixed stars. The spectrum from lamp-light appears deficient in three dark lines, D being replaced by a double bright one; the ray thus wanting in the solar spectrum, appears to correspond to the homogeneous light evolved during the combustion of alcohol, in which common salt has been dissolved, as in Brewster's monochromatic lamp.

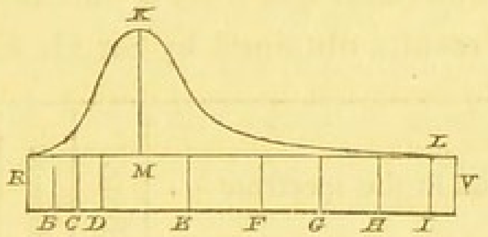
481. The great value of these fixed lines, is their enabling us to take very accurate measures of the refractive (445) and dispersive power (467) of bodies. The following is an abstract from the table of Fraunhofer's admeasurements of the

* This mode of observing the spectral lines was described by the late Dr. Ritchie, Phil. Mag., x., p. 183.

refractive indices of water, oil of turpentine, flint, and crown-glass, for the rays B to H inclusive (479):

Refracting Medium.	Names of Rays referred to.						
	B	C	D	E	F	G	H
Water 1st observation.	1·330935	1·331712	1·333577	1·335851	1·337818	1·341293	1·344177
Water 2d ,,	1·330977	1·331709	1·333577	1·335849	1·337788	1·341261	1·344162
Oil of Turpentine .	1·470496	1·471530	1·474434	1·478353	1·481736	1·488198	1·493874
Crown-glass 1st specn.	1·524312	1.525299	1·527982	1·531372	1·534337	1·539908	1·554684
Flint-glass 1st specn.	1·602042	1·603800	1·608494	1·614532	1·620042	1·630772	1·640373

482. The intensity of light in the solar spectrum appears to be greatest in the yellow band, and from that space it decreases to both extremities of the whole series of tints. Fraunhofer has exhibited these variations in the light of the different parts of the spectrum by a curve RKL, the ordinates of which indicate the intensity of light in the different parts of the spectrum RV, in which Fraunhofer's lines (479) have



been marked. Taking the ordinate KM falling nearly in the boundary between the yellow and orange as unity, the following will represent the illuminating power of the spectrum in the different portions occupied by Fraunhofer's rays; the red extremity being indicated by R, and the violet by V:

Parts of the Spectrum.	R	B	C	D	E	F	G	H	V
Intensities of light in K; M = 1	0·0	0·032	0·94	0·64	0·48	0·17	0·031	0·056	0 0

483. The calorific powers of the spectrum increase from the violet to the red extremity, and even extend beyond it, the obscure space bounding the red extremity possessing a higher temperature than the red band itself (H 467); so that it is evident, that when luminous undulations are propagated through a prism, a certain amount of them move with too little rapidity to communicate to the eye the sensations of light, and are only to be recognized by their calorific effects. These rays of non-luminous heat are less refrangible than the rays of red light, and are therefore found in the greatest abundance beyond the band of that colour.

These calorific rays have their situation altered according to the refracting medium of which the prism is constructed; being in the greatest number in the yellow band, when a prism of water; in the orange, when one of sulphuric acid; in the middle of the red, when one of crown glass; and beyond the red, when a prism of flint glass is used.

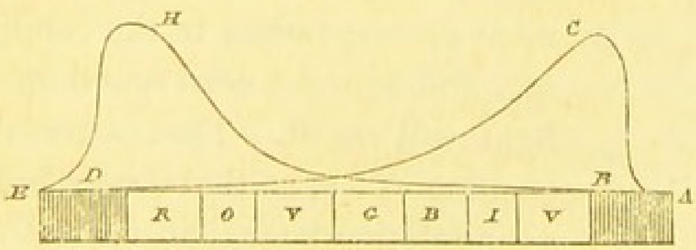
From the observations of Nobili and Melloni, on a spectrum produced by a rock salt prism, the highest temperature was found beyond the red, and about as far distant from it on one side as the blue band was from it on the other. The following were the results obtained by Sir H. Englefield:

Colour of band in the spectrum .	Blue.	Green.	Yellow.	Red.	Beyond the Red.
Temp. by Fahrenheit's thermometer	56°	58°	62°	72°	79°

484. The chemical action of solar light, in producing chemical combination and decomposition, has been long known, and this like the heating power appears to reside in greater intensity at one end of the spectrum than the other. This may be shown by dipping in a solution of nitrate of silver a slip of paper, previously washed over with a solution of common salt; on drying this, and exposing it to the action

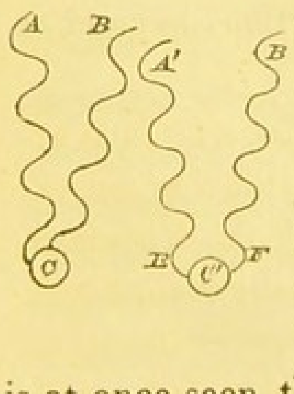
of the solar spectrum (147), a very remarkable effect will be observed. In the course of a few minutes the chloride of silver with which the paper was imbued, becomes of a deep slate colour in the violet, and in the sombre space beyond it; whilst in the yellow, orange, and red, it remains unaffected, its colour being less altered in the blue than in the violet, and scarcely at all changed in the green. Thus the chemical action of the different rays of the spectrum appears to be concentrated in the violet band, and in the dark space beyond it, at the directly opposite end to the seat of the calorific rays. So that there is reason to believe that those undulations which are propagated through a prism (467) with too great rapidity to act on the organ of vision, possess the power of exerting certain chemical effects on many substances, in the same manner that calorific effects are exerted by those undulations which move with too little rapidity to produce the sensation of light. Granting this, we meet with another circumstance in which the propagation of light by the undulation of ether, and of sound by those of air, correspond. For it has been already shown (195), that aerial waves moving with a velocity sufficient to strike the ear less than 32, or more than 1500 times in a second, are inaudible; whilst ethereal undulations, if less frequently repeated than 458 millions of millions, or more frequently than 727 millions of millions of times in a second, are incapable of acting on the visual organs.

485. If DB represent the solar spectrum produced by flint glass, and AB DE the non-luminous portions beyond it,



at each extremity, the curve EHB will give an idea of the position of the calorific rays, ACD and the position of the chemical rays. The longest ordinate of the curve EHB falls without the red ray R in the obscure space beyond it, where the calorific effects are most manifest; and the longest ordinate of the chemical curve ACD falls in the dark space beyond the violet ray V, where the action on chloride of silver appears to be most intense. Both curves rise abruptly, and gradually decline to zero at opposite ends of the spectrum.

486. When two or more undulations emanating from the same sources, act on a particle of ether, it oscillates with an intensity corresponding to the combined force of the undulations (422); the same thing occurs, providing the latter are of equal length, or differ by a given number of entire undulations, even when they emanate from different sources. But if the waves acting on a particle of ether differ by any fractional number of undulations, they interfere and oppose each other's action, and thus actually produce partial or total darkness. To render this more clear, if any number of rays produced by 1, 2, 3, or any whole number of undulations, act in concert, increase of effect is produced; but when a certain portion of the rays are produced by 1, 2, 3, or any whole number, whilst another set are produced by $1\frac{1}{2}$, $2\frac{1}{2}$, $3\frac{1}{2}$, or any fractional number of undulations, interference, and obscuration takes place, from the mutual checking of a certain number of waves. This is rendered obvious by drawing two sets of waves containing the same number of undulations as AB; any particle of ether at C must be made to assume a movement corresponding to the combined action of A and B, and a corresponding intensity of light will result. Then alter the relative position of AB, so that A may begin one half an indulation later than B, as at A′B′, then it is at once seen that they will be always in opposite phases;



for any particle of ether at C will be acted on in opposite directions by A′B′; for whilst the undulation F is moving from right to left, E is moving in an opposite direction, and mutually opposing, they will cease to act on a particle of ether at C, producing darkness by the conflict of two luminous undulations. If the waves of light, instead of meeting at the end of an entire half-undulation, encounter at any fractional part of one, partial interference will ensue, and colours will be developed, bearing a relation to the length and velocity of the undulation remaining undestroyed.

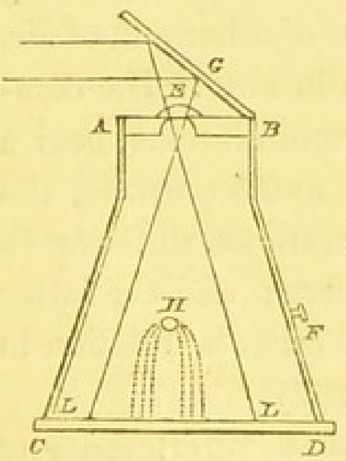
In this explanation of the interference of luminous waves of ether, it must be borne in mind that the series of progressive undulations here figured are assumed merely for the sake of facility of demonstration, as it has been already pointed out (422) that undulations of highly elastic media, as ether, consist of a series of alternate expansions and contractions in opposite directions of spherical molecules, and not of any truly progressive movements.

487. We have already seen that the interference of sonorous undulations produce silence (188); and in the extension of this fact to luminous waves, we meet with a striking analogy between the oscillations of particles of ether and of air, the difference being rather in degree than in kind. The combined or diminished action of luminous undulations, bear a remarkable relation to musical discords and concords, the former being produced when sonorous vibrations, differing in their rapidity by fractional portions, interfere; and the latter when similar vibrations, bearing to each other a relation in whole numbers, strike the ear together (197).

488. An experimental demonstration of the interference of luminous undulations may be obtained, by placing on a smooth table two pieces of plate glass cut from the same piece, with their divided faces in contact. Gently incline one towards the other by placing a piece of paper under its edge, and allow a ray of homogeneous light (467) to fall upon

them, taking care to shut out all extraneous light from the room. If the light be yellow, as that emitted from a spirit-lamp with a salted wick, a series of yellow and black bands will be seen on the glasses, the bright ones arising from the undulations propagated from one mirror to the other in such a manner that they are in the same *phase* (422), and the dark one when in opposite *phases*, and consequent production of interference. This experiment was first proposed by M. Fresnel.

489. An interesting set of illustrations of the doctrine of luminous interference, is met with in the phenomenon of diffraction discovered by Grimaldi, a Jesuit of Bologna. To observe these properly, a beam of diverging light is necessary; this may be obtained by making a small hole in a window shutter, and receiving the light on a screen at the distance of some feet. If a convex lens, of small focal length, be fitted in the hole in the shutter, the light is refracted almost to a point, from whence it diverges in a manner extremely fitted for experiments on diffraction. For small experiments, a pyramidal box, ABCD, about two feet long, and blackened inside, may be advantageously employed; at E, a convex lens, of an inch focus, is fixed, on which, by means of the plane mirror G (432), a sunbeam can be readily thrown. The light is refracted by the lens to a point, and then diverging, is received on a sheet of white paper placed at the bottom of the box; by means of a door shown at F in the section, the bottom becomes easily visible, without admitting any quantity of extraneous light.



490. If any small opaque bodies, as hairs, pins, &c., be held in the beam of diverging light, ELL, their shadows will be thrown on the bottom of the box, surrounded by coloured

fringes. If H be a section of a pin thus exposed, the fringes are seen surrounding its shadow, as though they were produced by coloured rays passing by its margin, not in straight lines, but in hyperbolic curves, as shown by intercepting them at different distances by a piece of card; when their decrease in extent will be found to be much more gradual than if the light passed by H in right lines. Besides their external fringes, there are internal ones within the shadow, which, if the body be narrow, as a pin, becomes completely filled with them. These colours are, as Lord Brougham* has long ago shown, in harmonic proportion, like those of the solar spectrum (468). The tints of the coloured fringes, reckoning from the shadow, succeed each other in the following manner:

1st fringe—violet, indigo, blue, green, yellow, red.

2d fringe—blue, yellow, red.

3d fringe—pale blue, pale yellow, red.

If *homogeneous* light (467) be employed, the fringes will be of the same colour as this light, and their intervals will appear black. The fringes are broadest in red, narrowest in violet, and of intermediate breadth in the other colours of the spectrum.

491. These phenomena admit of ready explanation on Dr. Young's theory of interference, for the diverging light which passes by one side of the pin (490), meeting with that passing on the opposite side, coincide, and produce a line of white light, which ought to occupy the middle of the shadow. Whilst those rays which differ in their paths, as those produced by undulations, which pass obliquely past the pin *into* its shadow meeting with those which pass more directly on the opposite side, being of course unequal in their paths, encounter under different phases (422), and interfere (486), either checking the undulation entirely, and producing

* Phil. Transactions, 1796.

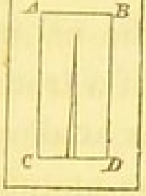
darkness, as when homogeneous light is used, or so partially checking it as to allow such a number of movements to be executed in a given time as shall be sufficient to produce a coloured fringe.

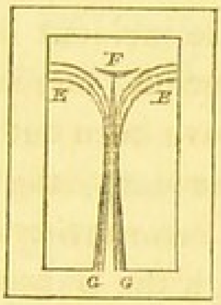
492. In shadows of this kind, formed by narrow bodies, the middle is always occupied by a luminous line, as though the light had passed directly through the centre of the diffractory body. This very curious fact is best observed by holding a small disc of metal on a slip of glass, in the diverging light (489); the rays passing by its circumference are inflected, and meet, after traversing equal paths, in similar phases in the centre of the shadow, producing a brilliant spot of light. The shadow thus precisely resembles that of a circular disc perforated in the centre. This beautiful experiment is best performed by means of a drop of thick black ink, or a mixture of lampblack and size, placed on a plate of glass, so as to form a circular spot about the tenth of an inch in diameter. For this modification of the original experiment of Fresnel, we are indebted to Prof. Powell.

493. If a disc, perforated with a very small hole in the centre, be held in the beam of diverging light (489), the converse of the last experiment will be observed; for those undulations which pass directly through the aperture, interfere with those passing more obliquely, and produce a dark spot on that part of the shadow corresponding to the hole in the disc. Thus, by the mutual interference of luminous undulations, we find light virtually changed to darkness, and darkness to light, by the *discord* or *concord* of the luminous waves.

494. If two knife edges be held very near each other in the beam of light (489), beautiful coloured fringes will be observed to border their shadow, and a dark line will, if they be sufficiently near, be seen to occupy the middle of the space, at which they are really separate. This result of luminous interference may be readily shown by fixing a slip of tin-foil on a plate of glass, and dividing it longitudinally;

very slightly separate the divided portions at one end, so that they may form a very acute angle with each other, as at ABCD.





Hold this in the diverging light of the apparatus before described (489), about six inches from the bottom, so that it may form a well-defined shadow. The centre of the shadow, corresponding to the slit in the tin-foil, will be marked by an obscure line, and the shadow from this line will be covered with a beautiful set of fringes diverging from each other as they approach the apex of the acute angle F, formed by the foil, bounded on each side by hyperbolic curves, with their convex surfaces towards each other, as if diverging from vertices situated at EE. So that the widest parts of the curved fringes correspond to the apex of the angle formed by the slips of tin-foil. In the figure, FGG, represent the projection of the slit in the foil on the paper on which the shadow falls. This experiment is an easy and rough mode of repeating Newton's observations with the knife-blades.*

495. The phenomena of diffraction may be observed on a small scale in the manner recommended by Prof. Powell, by stretching a fine wire across, and in contact with a small lens; holding the outer surface next the eye, look through it at the light of a candle, admitted through a narrow slit. The dark image of the wire will be seen edged by the external, and the shadow marked by the internal fringes (490), in a very beautiful manner.

* Optice. Lib. iii., pars. i., obs. 10.

496. The explanation of the cause of colours by diffraction (491) is finely illustrated by placing a card on one side, and on a plane above or below the body H (489), so as to intercept some of the incident or diffracted light; the fringes then disappear, because one set of the undulations producing interference have been cut off. If a transparent body be substituted for the card, the fringes undergo a remarkable change, from the *retardation* of those undulations which are propagated through the transparent screen.

497. The brilliant tints of soap-bubbles, and thin plates of different transparent bodies, afford other examples of interference of light; for the undulations reflected from their first surfaces interfere with those reflected from the second (431*); and upon the amount of retardation thus experienced by the luminous waves, the varieties of colours observed in these thin plates depend. The colours of soap-bubbles are best seen by boiling a small quantity of soap with distilled water in a bottle, and corking it whilst boiling hot. The whole being secured from air, is allowed to cool, and on adroitly shaking the bottle, a large bubble, presenting the coloured bands with great beauty, may be readily formed; this bubble is permanent for several hours, and affords every facility for examining its tints.

498. The colours of thin plates of air may be observed by pressing a convex lens on a plate of glass, and holding it in the light, so that rays reflected from it will pass to the eye. At the point of apparent contact of the lens and glass, a black spot will, under these circumstances, be visible; this is surrounded by a great number of rings of different colours, each series of tints consisting of fewer colours as they recede from the centre. On holding the glasses between the eye and the light, a set of rings will be observed, differing in colour from those seen by reflection; and, *complementary* to them, each ring possessing that colour, which, by mixing with the tint of the corresponding reflected ring, would produce white light.

The following are the colours of the rings, observed by reflection and transmission, commencing from the centre or point of apparent contact, as given by Sir Isaac Newton.* The curved line CA represents the section of one half the convex lens, and the straight one CB that of half the plane glass against which it is pressed.

C

Transmitted Rings.	*Reflected Rings.*
White	Black,
Yellowish Red .	Blue,
Black............	White,
Violet	Yellow,
Blue	Red,
White	Violet,
Yellow	Blue,
Red	Green,
Violet	Yellow,
Blue	Red,
Green............	Purple,
Yellow	Blue,
Red	Green,
	Yellow,
Greenish Blue	Red,
Red	Green,
Bluish Green	Red,
Red	Greenish Blue,
	Red.

B A

499. The following are the thicknesses, expressed in millionth parts of inches, of plates of air, water, and glass, required to produce the different coloured rings:

* Optice. Lib. ii., pars. 2.

Series of Colours.	Colours seen by Reflection.	Thickness of Plates producing them. Air.	Water.	Glass.
First	Very black	0·50	0·38	0·33
	Black	1 00	0·75	0·66
	Blackish	2·00	1·50	1·30
	Pale sky-blue	2·40	1·80	1·55
	White (like polished silver)	5·25	3·88	3·40
	Straw colour	7·11	5· 3	4·60
	Orange-red (dried orange-peel)	8·00	6·00	5·17
	Red (geranium sanguineum)	9·00	6·75	5·80
Second	Violet (vapour of iodine)	11·17	8·38	7·20
	Indigo	12·83	9·62	8·18
	Blue	14·00	10·50	9·00
	Green (that of the sea)	15·12	11·33	9·70
	Lemon-yellow	16·29	12·20	10·40
	Orange (fresh rind of oranges)	17·22	13·00	11·11
	Bright red	18·33	13·75	11·84
	Dusky red	19·67	14·75	12·66
Third	Purple (flower of flax)	21·00	15·75	13·05
	Indigo	22·10	16·57	14·25
	Prussian blue	33·40	17·55	15·10
	Grass-green	25·20	18·90	16·25
	Pale yellow	27·14	20·33	17·50
	Rose-red	29·00	21·75	18·70
	Bluish-red	32·00	24·00	20·66
Fourth	Bluish-green	34·00	25·50	22·00
	Emerald-green	35·29	26·50	22·80
	Yellowish-green	36·00	27·00	23·22
	Pale rose-red	40·33	30·25	26·00
Fifth	Sea-green	46·00	34·10	29·66
	Pale rose-red	52·50	39·38	34·00
Sixth	Greenish-blue	58·75	44·00	38·00
	Pale rose-red	65·00	48·75	42·00
Seventh	Greenish-blue	71·00	53·25	45·80
	Pale reddish white	77·00	57·57	49·66

By aid of this table, the thickness of thin films of air, water, or glass, may be readily determined by observing the colours they reflect. The comparative thickness of plates of two substances, reflecting the same colour, are in the inverse ratio of their indices of refraction (445).

500. When these rings are observed by homogeneous light, they present the same hue as that of the light itself; alternating with dark and almost non-luminous rings, they appear to possess the greatest breadth in red, and the least in violet light. These rings appear to be larger, in proportion as we look at them in a more oblique direction; this is best seen by examining the rings produced, when a glass prism is pressed on the surface of a convex lens.

The coloured rings* thus exhibited by thin plates, are produced by the interference of the light reflected by the first surface with that reflected from the second (431*); for when either of these reflected rays is intercepted, the colours entirely vanish.

501. The rings seen by transmission, are produced by those undulations which are not reflected, and are consequently propagated through the thickness of both glasses. Those luminous rays, which, when combined with the reflected rays, produced white light, being propagated through the glass, produce the transmitted or complementary (498) rings.

From Newton's table (499), we see that air, at or below a thickness of half a millionth of an inch, and water and glass at a thickness of about one third of a millionth of an inch, cease to reflect light, and appear, consequently, black. Films and fibres of quartz, so minute as not to be capable of propagating luminous undulations, have been met with and described by Sir David Brewster.

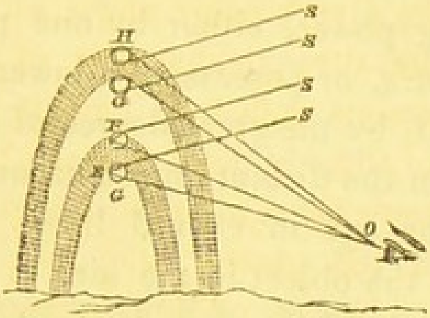
502. It is by no means necessary that very thin plates should be used to exhibit colours, for plates of any thickness, so arranged as to cause the interference of luminous undulations, will produce the same effect. This may be shown by fixing two slips of plate glass, about 0·10 inch distant from

* These rings may be exhibited by merely placing two plates of window glass, about four inches square, together, and passing them in the centre by means of a pointed piece of metal. The different coloured rings, somewhat eccentrically arranged, will appear with great beauty around the point where the pressure is applied.

each other, by means of two pieces of wax, and then by pressing one end of each plate together, they may be so fixed as to describe a very acute angle with each other. On looking at a candle, through that part of the plates nearest each other, numerous reflected images of it will become visible ; the first of them appears crossed by a series of beautiful bands or fringes. These increase in breadth by diminishing the inclination of the plates; they are produced by the interference of the waves of light reflected from both surfaces of each glass plate.

503. The coloured rings, observed by regarding the sun, or other luminous body, through a piece of glass, covered with minute particles, as of dust, lycopodium, &c., or of water, by breathing on it, are all owing to the interference of luminous undulations inflected round the particles (490). A similar explanation will apply to the colours seen, by scattering fine powders or dust on, or before a mirror exposed to the solar rays. The beautiful tints presented by mother of pearl, and other natural or artificial substances, whose surface are marked by minute striæ, are all explicable on the hypothesis of interference; all that is requisite to produce these colours being, that the depression shall be of such a depth, as to cause an alteration in the path of rays incident upon them, equal to a fraction of the length of an undulation (486).

504. Among the natural phenomena which serve to illustrate the laws and principles laid down in this and the preceding chapters, the well-knownrain bow and less frequent mirage especially deserve attention. The former consists of a coloured arch, apparently suspended in the sky, and opposite to the sun, and is usually composed of two bows, termed primary and secondary, and sometimes even of other supplementary arches. The rainbow is never seen unless a shower of rain is falling, or the spray of water, as from a cataract, rising between the spectator and that portion of the sky opposite to the sun. To explain the cause of these bows, let FE be two drops of water, and SS solar rays incident upon



each of them, those which enter near their centre will be refracted to a focus, as in a sphere of glass (453). But those which enter near their upper part suffer refraction, during which the light becomes resolved into waves of different lengths, as in prismatic refraction (467), and colours are consequently produced; the violet ray being most, and the red least refracted, the other rays being arranged between them in the usual manner. As these refracted rays are incident at the back of the drop, within the limiting angle (448), they are reflected, and emerge at the lower parts, as G in the drop E, and present to the eye of the spectator a bow of the prismatic colours, bounded above by the red, and below by the violet rays.

When the solar rays enter the drops of rain from below, as at GH, they are refracted to the back of the drop, and undergo the same resolution into coloured rays; thence are reflected to the top, and thence to the front of the drop, where they emerge, presenting to the spectator the appearance of a second bow, exterior to the first, and with its tints much fainter and reversed, in consequence of the rays having suffered two reflections in GH, whilst in FE they underwent but one.

505. If an object, situated at or near the horizon, be so far from us, that, in consequence of the curvature of the earth, a right line could not connect it with the eye of the spectator, it will be invisible, except under a few remarkable states, constituting the phenomena of *unusual refraction.* For the production of these effects, it is necessary that the

strata of atmosphere near the earth should differ considerably in refracting power, either by one portion being more loaded with vapours, or possessing a lower temperature than the other; so that, by the great degree of refraction to which rays passing from the distant object become submitted, they virtually reach the eye in curved lines, and the spectator sees an image of the object in the air, in the direction of a tangent to these curved lines, and inverted, in consequence of the altered relative position of the rays passing between the object and the spectator.

Phenomena of this kind, constituting the *mirage*, or *fata morgana* of the Italians, are occasionally seen in great splendour in the straits of Messina. In the north of Europe, and in several parts of Great Britain, the mirage has been frequently observed, and is by no means of rare occurrence on the English coast, in the evenings of hot autumnal days.

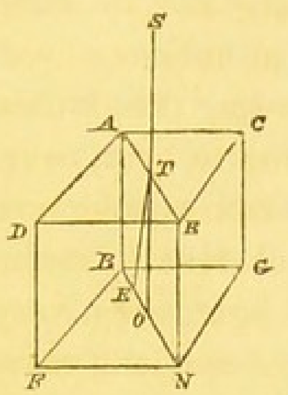
506. Some of the conditions for the production of the mirage may be observed by regarding a small object, through the point of mixture of two fluids of different densities, as syrup or alcohol, and water, when images will be seen on a plane higher, and in an inverted direction, with regard to the original object. The same effect may be observed by looking at an object across a red hot iron, or over a charcoal chauffer; or, still better, on a cool day, by regarding a distant wall or tree over the boiler of a steam-carriage. The wall or tree will appear to be divided into several portions, and surmounted by inverted images visible for a considerable space above the source of heat.

CHAPTER XXIII.

POLARIZED LIGHT.

Ordinary and extraordinary Rays by Double Refraction, 507. *Principal Section of Crystals*, 508. *Doubly Refractive power of various Bodies*, 509. *Positive and Negative, Real and Resultant Axes of Double Refraction*, 510. *List of Positive and Negative Crystals*, 511. *Huygenian Law of Rapidity of the two Rays*, 512. *Intensity of Refractive Power in different parts of Crystals*, 513. *Crystals with Two Axes*, 514. *Action of Crystals on Coloured Light*, 515. *Doubly Refractive Power acquired by Change of Structure*, 516. *Polarized Light*, 517. *Planes of Polarization*, 518. *Different Modes of Polarizing Light*, 519—*by Refraction through Iceland Spar*, 520—*by Absorption*, 521-2—*by Reflection*, 523. *General Properties of Polarized Light*, 524-6. *Polarization by Refraction through Glass-plates*, 527. *Partial Polarization*, 528-29. *Ratio between Polarizing Angle and Refractive Index*, 530-1. *Polarization by Internal Reflection*, 532. *Polarization of Homogeneous Light*, 533. *Polarization by a Bundle of Transparent Plates*, 534. *Polarized Light, in Common Daylight*, 535.

507. So far as we have yet examined the properties of light, we have learnt that when a ray is incident upon the surface of any refracting substance in a perpendicular direction, it undergoes no change in its course; but when incident obliquely, it becomes refracted according to a law already detailed (443). We have now to notice some very remarkable properties of a class of refracting media, capable of dividing an incident beam into two portions differing from each other in their physical properties.



Let ABCDFGN be a rhomboid of Iceland spar (carbonate of lime), and a ray of light ST be incident upon one of its surfaces, in a perpendicular direction; instead of passing through without refraction, it will be divided into two rays, one TO being in the direction of the original ray, ST, and consequently unrefracted, and another, TE, which is refracted towards the angle B. If the ray ST, instead of being incident in a direction perpendicular to one of the faces, were oblique, it would, on entering the crystal, be refracted into two rays, one of them obeying the ordinary law of refraction (443), and the other, following a different law, becoming refracted towards an imaginary line connecting the two acute angles EB. The former is termed the *ordinary*, and the latter the *extraordinary* ray.

508. This double refraction of incident light by a rhomb of Iceland spar, may be seen by placing a black wafer, pierced with a small hole in its centre, on the face AE of the crystal. Then, holding the latter between the eye and the light, so that the spectator may look through the thickness of the crystal at the wafer, he will see two holes, from the light entering the aperture in the wafer dividing into two rays before it reaches the eye: on turning the crystal round, whilst the wafer remains fixed, one of the spots of light will appear to revolve round the other.

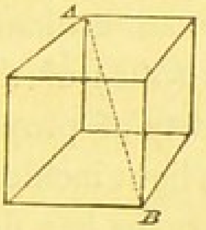
A rhomb of Iceland spar, placed upon any object, as a line drawn on paper, will cause it to appear double, in consequence of this property of double refraction.

In the rhomb of spar, the plane, AEBN, passing through the crystal, and dividing it into two triangular prisms, is termed the *principal section* of the rhomb.

509. The property of resolving undulations propagated through them into two series differing in velocity (512), and consequently producing double refraction, is not confined to

the varieties of carbonate of lime, but belongs in general to all crystals whose primitive form is neither a cube nor an octohedron. A vast number of crystals, as well as uncrystallized diaphanous substances, if not already possessing the double refracting structure, will assume it by exposure to heat, cold, compression, induration, and various other causes affecting their molecular arrangement (516). Some substances, as the tourmaline, are capable of doubly refracting light, when very thin, and act in the ordinary manner upon incident rays, when they are thick.

510. In all doubly refracting bodies, there are one or more directions, along which objects, when viewed through them, appear single; these are termed the *lines, or axes of double refraction.* In the case of Iceland spar, there is but a single axis of double refraction, in the direction of a line connecting its two obtuse trihedral angles, as shown by AB in



the marginal figure. The axis of double refraction is not a fixed line, but merely indicates the direction of a plane, in which double refraction is absent; for if a rhomb of Iceland spar be split into any number of smaller ones, each will possess its own axis of refraction. It occasionally happens that no double refraction exists in the axis of a crystal, in consequence of the presence of two doubly refractive forces neutralizing each other, as in mica; this is then termed the *resultant axis,* in contra-distinction to the real axis of double refraction. The course of the extraordinarily (507) refracted ray is constant for each crystal, with regard to the axis of double refraction, being refracted either towards it as in quartz, or from it, as in Iceland spar. Those crystals in which this ray is bent towards the axis, are said to have a positive, and when bent from it a negative, axis of double refraction.

511. In all crystals with one axis of double refraction (510), it corresponds with the geometric axis of the crystal, including, according to Sir David Brewster, all those bodies which

crystallize in rhomboids, regular hexaëdral prisms, and octoëdrons, or right prisms with square bases. The following are some of the crystals possessing one axis of double refraction :

A. Positive Axis.	B. Negative Axis.
Dioptase.	Iceland spar.
Quartz.	Tourmaline.
Zircon.	Sapphire.
Titanite.	Emerald.
Apophyllite.	Ferrocyanide of potassium.
Ice.	Ammoniaco-phosphate of magnesia.
Potass-sulphate of iron.	Mica (some specimens).
Boracite.	Cyanuret of mercury.

512. When a rhomb of calcareous spar is placed upon a line drawn on paper, the greatest separation of the two rays, and consequently of the images, occurs, when the line is parallel to the great diagonal of the crystal ; and, on turning the latter round, the images gradually approach, and alternately merge into each other when the line on the paper is parallel to the shortest diagonal, as the extraordinary and ordinary rays are then placed in the principal section (508) of the crystal. With regard to the comparative rapidity of propagation of the two sets of undulations into which light incident on a doubly refracting crystal is resolved, Huygens has demonstrated that the difference between the squares of the rapidity is equal to unity divided by the square of the sine of angle formed by the ray with the axis. In calcareous spar the ordinary ray therefore moves with a greater velocity than the extraordinary one.

513. If uni-axial doubly refracting crystals (511) be supposed to be shaped into spheres, of which the axis connecting the poles correspond to the axis of double refraction in the original crystal, in positive refracting crystals as quartz, the index of extraordinary refraction increases from the pole to the equator of the sphere ; whilst in negative refracting crystals, as calcareous spar, the index decreases from the poles or termination of the axis, to the equator at right angles to them.

In a sphere of calcareous spar the index of refraction of both rays will be the same, or 1·654, if light be transmitted along the axis; at 45° from the latter, the index for the extraordinary ray will be 1·572, and at 90°, viz. at the equator, the index decreases to 1·483, from which point it increases to the opposite pole. In a sphere of quartz, the index of refraction for both rays will at its axis be 1·5484, and at the equator the index of the ordinary ray remaining the same, that of the extraordinary one increases to 1·5582.

514. A large number of crystals, including those whose primitive forms are right, or oblique prisms with rectangular, rhombic, or oblique quadrangular bases, as well as octoëdrons with rectangular or rhombic bases, possess two axes of double refraction. These axes do not correspond to any prominent lines in the crystal, and form various angles with each other; from the most acute, to one of 80·30, as in carbonate of potass, and to a right angle as in sulphate of iron. The following list contains the names of some of the most important double-refracting crystals, with the measures formed by the inclination at their axes on each other, taken from a large table by Sir David Brewster:

A. Principal Axis of double Refraction. Positive.		B. Principal Axis. Negative.	
Names.	Angles formed by Resultant (510) Axes.	Names.	Angles formed by Resultant Axes.
Sulphate of nickel	3° to 42° 4′	Nitrate of potassa	5 20′
Biborate of soda.........	28 42′	Carb. strontia	6 56
Sulphate of baria.........	37 42	Talc	7 24
Spermaceti	37 40	Carb. lead	10 35
Heulandite	41 40	Mica, certain specimens	14 0
Soda-sulphate of magn.	46 49	Sulph. magnesia	37 24
Brazalian topaz	49 to 50	Carb. ammonia	43 24
Sulphate of strontia.....	50	Sulph. of zinc	44 28
Sulphate of lime	60	Sugar	50
Nitrate of silver	62 16	Phosphate soda	55 20
Scottish topaz	65 0	Tartrate potass	71 20
Sulphate of potass	67 0	Tartaric acid	79
Potass-tartrate of soda...	80 0		

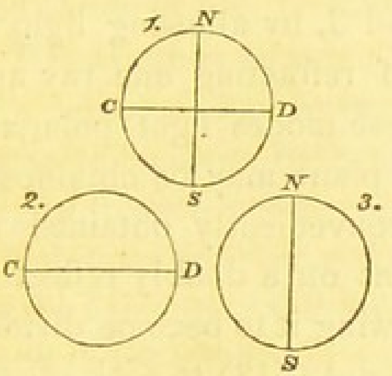
515. In crystals with two axes of double refraction, the ray, equivalent to the ordinary ray (507), differs from that properly so called, as it does not obey the law of sines (443); so that the two sets of undulations, into which common light is resolved by a biaxial crystal, are both to be considered as producing extraordinary rays. This observation we owe to M. Fresnel. Crystals are occasionally met with possessing two axes of double refraction, for light of one colour, and but one axis for light of another tint; thus, Sir David Brewster found that glauberite possessed two axes mutually inclined at an angle of 5° for red light, and but one axis for violet light. Sir J. Herschel found that the axes occasionally vary in inclination, according to the kind of light; thus, in the potassio-tartrate of soda, the inclination of the axes for violet light is 56°, and for red light 76°. In nitrate of potass, the inclination of the axes for violet light is greater than for red.

516. When glass is unequally heated, or suddenly cooled, it assumes a doubly refracting structure, the axes being variously situated, according to the shape of the substance. A solid cylinder of glass, heated by being plunged into hot oil, acquires a doubly refractive power, having one positive axis in the position of its geometric axis; and if previously heated and plunged into cold oil, it acquires a similar property, but its axis becomes negative (510). In both these cases, the refracting power is transient, and vanishes as soon as all the parts of the cylinder have acquired the same temperature. A sphere of glass, similarly treated, becomes double refractive, but with innumerable axes, as is naturally the case in analcime, in which the axes are almost infinite. The crystalline lenses of all animals possess one or two axes of double refraction.

517. In the preceding chapters, we have regarded colourless light as the same after, as before refraction or reflection; and the only modifications of it which we have examined, are its resolution into several series of undulations varying in length and velocity, as in prismatic refraction (467) and dif-

fraction or inflection (489); and its resolution into two series only, producing coloured rays complementary to each other (498), as when white light is resolved into green and red, or yellow and violet. We have now to examine the changes undergone by a ray of light after it has been resolved into two series of colourless beams, as after refraction through a rhomb of Iceland spar (507).

To understand these new properties of light, we may conceive every beam to be hypothetically produced by two sets of undulations, moving in a direction at right angles to each other.* Let fig. 1 represent a section of a beam of common light, consisting of two rays CD, NS, at right angles to each other. Light thus constituted possesses all the properties detailed in the preceding chapters; and when allowed to be refracted through a rhomb of Iceland spar, its rays become separated; one of them, as CD, fig. 2, constituting the ordinarily, and the other, NS, fig. 3, the extraordinarily refracted ray (507). Thus, by refraction through the crystal, the luminous undulations have become resolved into two colourless series at right angles to each other; when combined, as in fig. 1, they constituted common; and when separated, as in figs. 2 and 3, they constituted polarized light, so called because they assume new and peculiar properties with regard to each other, and different refracting or reflecting media.



518. The rays NS differ from those CD only in their position; for by causing them to coincide, as by moving CD (fig. 1), until it coincides with NS, we obtain a ray possessing the same

* This very convenient mode of illustrating the phenomena of polarization is a direct expression of the phenomena of the reflection or refraction of polarized light, according to the direction of the planes (524), and was first applied by Sir David Brewster.

properties, but twice as intense as each separately. Planes passing through CD, NS, are termed *planes of polarization ;* and the rays CD, NS, (figs. 2 and 3,) are said to be polarized in different planes.

If the two separated rays NS, CD, (figs. 2, 3,) be reunited, as in fig. 1, they will reproduce *ordinary, common, or unpolarized light ;* all these terms being synonymous.

519. From a bare inspection of the above figures (517), we see that polarized light may be obtained from common light in different ways; 1, by turning round one of the rays until it coincides with the other; 2, by passing the light through some substance capable of absorbing or checking one ray, and transmitting the other; and 3, by allowing light to be incident on a medium capable of refracting one ray and reflecting the other. By any of these modes light polarized in a rectilinear direction and in one plane may be obtained.

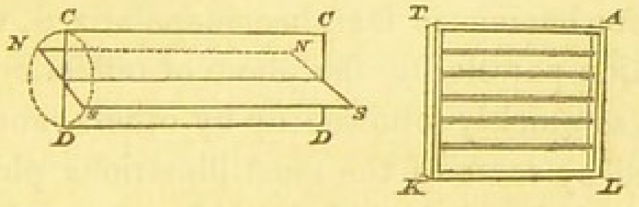
520. Polarized light is very conveniently obtained by allowing common light to be incident on a doubly reflecting crystal, as calcareous spar, and allowing it to become divided into two beams polarized at right angles (518) to each other ; we can, by sticking a wafer or a piece of black paper over the point of emergence of one beam, obtain a ray of light polarized in a direction perpendicular to that which is checked or absorbed by the wafer. When light suffers double refraction through a crystal with a positive axis (510), as quartz, the plane of polarization of the ordinary ray (507) is horizontal, and that of the extraordinary ray vertical. In negative crystals, as Iceland spar, the direction of these rays is reversed. When the plane of polarization (518) of a polarized beam of light is incident in a direction parallel to the principal section (508) of the doubly refracting crystal, it is refracted in the ordinary manner; obeying the extraordinary beam (507), when it is incident at right angles to the principal section.

521. When a ray of common light (518) is incident on a thin and transparent plate of agate, cut in a direction per-

pendicular to its siliceous layers, one of its constituent rays, as CD, (fig. 1, 517,) becomes dispersed in a nebulous manner, whilst the other NS is transmitted. This transmitted ray is polarized in a given direction, with regard to the position of the layers of which the agate is composed; and by turning the plate of that mineral round, so as to be at right angles to its former position, the ray CD polarized in a different plane to NS, is transmitted, and NS in its turn dispersed. This mode of obtaining polarized light is extremely convenient, but does not completely separate a beam of light into two polarized rays, unless the agate be of sufficient thickness and the light not too intense.

The siliceous minerals called tourmalines, especially those of a yellow or hair brown colour, when cut into thin plates, separate incident light into the two rays polarized at right angles to each other; one of which is transmitted, and the undulations producing the other become checked or absorbed by the mineral. On turning the plate of tourmaline round through the quarter of a circle, it transmits a beam polarized in an opposite plane to that of the one previously transmitted, and absorbs that ray which it transmitted when in its former position.

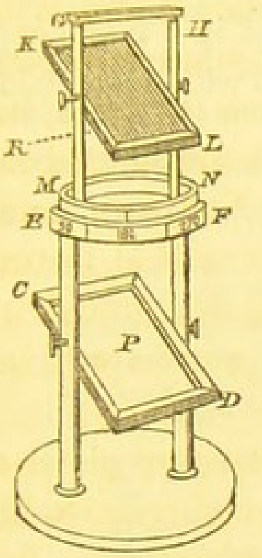
522. The action of a tourmaline, or agate plate, on common light, may be familiarly illustrated by fixing two slips of pasteboard in a direction at right angles to each other, as NS, CD, representing respectively the two, hypothetically constituent, beams of common light; let TAKL be a small frame of



wood, having a number of wires fixed across it, as shown by the dark lines in the figure. If TA be supposed to represent a plate of tourmaline or agate, and the paper figure NCDS a ray of light, approach it to TA, in the position shown in the figure, and attempt to thrust it between the transverse bars. The slip of paper NS will readily pass between the wires, but CD will be checked; NS will here represent a transmitted ray of light polarized in a given plane (518). Now turn round TA, until the direction of the wires becomes vertical instead of horizontal, then try to push the paper figure through it; the vertical slip CD will then pass through, and NS will become checked.

By this little apparatus, the action of polarizing plates of agate or other minerals, acting in the same manner, is readily impressed upon the memory, and as easily understood. But it must not be forgotten that the comparison of a set of transverse bars to a tourmaline plate is strictly hypothetical, and although valuable as pointing out particularly the effects of a tourmaline or agate in different positions on a beam of light, yet must not be considered as presenting a correct view of the real *modus agendi* of such polarizing plates on common light.

523. The mode of obtaining polarized light by reflection, was first discovered in 1810, by the celebrated philosopher Malus, an officer in the French engineers. M. Malus, whilst examining the light reflected from the windows of the Luxembourg, through a rhomb of calcareous spar, observed that light, when reflected from the surface of glass at an angle of 56°, acquired the very same properties as one of the beams obtained by submitting light to double refraction in calcareous spar; having, in fact, becomepolarized, with its plane of polarization parallel to the plane of reflection. This discovery was so quickly followed up by others, and so successfully studied by some of the most illustrious philosophers of the age, that it has led to the development of some of the most beautiful and important series of facts that have ever been discovered. The most convenient mode of repeating the experiments of Malus, is by means of the apparatus figured in the margin.



This consists of two uprights of wood, supporting a frame CD, constructed like a common looking-glass frame. A circular plate of wood EF rests on the pillars, and has a circular aperture in the middle about three inches in diameter; a ring of wood MN, moveable round a circular projection on EF, supports two pillars GH, between which rests by means of screws a frame KL, like CD, but some what smaller. A circular slip of paper graduated into 360°, is fixed on that portion of EF which projects beyond MN, a black line being marked on the latter, to serve as an index, and point to zero on the graduated paper, when the pillars GH are exactly over AB, and the frame KL placed so as to regard CD. A plate of glass rests over the aperture in the centre of EF, to serve as a stage on which objects to be submitted to the action of polarized light are placed.

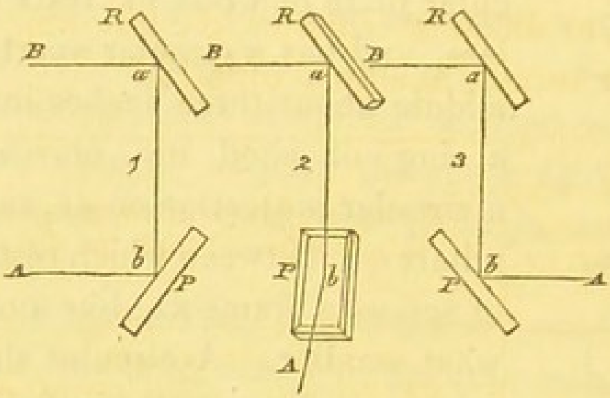
Into each of the frames CDKL, a smooth pane of glass PR, covered on one side with some black opaque paint, as a mixture of lampblack and size, is fixed, in the same manner as glasses are in ordinary mirrors. Of course the uncovered surface of the glasses is exposed to the action of the light, the painted side being protected by a piece of blackened wood or pasteboard (534).

This instrument, which was first suggested by M. Biot,* is the most convenient that can be used for experiments on polarized light; it may be conveniently termed a Polariscope.

524. Place a lighted candle at a short distance from the plate P (523), and adjust the latter so that the light may be incident upon it at an angle of 56° 45′. Then by means of the side screws fix the upper plate R, so that the ray reflected from P is incident upon that at the same angle of 56° 45′. The sections of the plates showing their relative position are shown

* Précis de Physique, tom. ii., p. 475. Paris, 1824.

in fig. 1. Light, on being incident on P, in the direction AP, is resolved into two portions, one being polarized in a plane perpendicular to the plane of reflection, and mixed with much com-



mon light (518), passes through the glass P, and is *absorbed*, from the undulations being checked by the black paint with which its back is covered. The other portion, polarized in an opposite plane, is reflected to R, and thence to the eye of the spectator at B, who of course sees an image of the candle in R. Then turn round the plate R, still keeping it at the same angle, by moving the collar MN on the wooden collar EF (523), and when R is at right angles to P, as in fig. 2, the image of the candle will almost entirely vanish. This might be indeed anticipated, for the ray polarized by reflection from P, is reflected polarized in the plane of reflection; and on placing R at right angles to P, the ray passes through the glass, and becomes absorbed by the black paint at its back. So that, on looking at R in this position, scarcely a vestige of light is to be seen reflected from it. On moving R round for another angle of 90°, as at fig. 3, the light and figure of the candle will reappear in R, as the planes of polarization (518) and reflection coincide, being both contained in a plane passing through APRB. At intermediate arcs of rotation, the light in R will decrease or increase in intensity, according as it approaches or recedes from the position shown in figs. 1 and 3. In these three figures, A*ba* shows the position of the *planes of primitive polarization*, and *ba*B the position of those of reflection.

525. Let R and P be fixed in the position shown in fig. 1 (524), the index on MN will point to zero on the graduated circle (523); and on watching the intensity of the light reflected from R, at different azimuths, the following effects will be observed on turning R slowly round :

Inclination of Planes of Reflection, as shown by the graduations on EF (529).	Varying brightness of an image of the candle reflected from the plate R.
0o	Greatest intensity of light.
0°—90°	Light decreases until it nearly vanishes.
90°—180°	Gradually increases in intensity.
180°	Regains the intensity it possessed at 0°.
18°—270°	Same as from 0 to 90.
270°	As at 90°, scarcely visible.
270—360°	Gradually increases, as from 90°—180o.

The light reflected from R, decreases in the ratio of the squares of the cosines of the angles formed by the planes of polarization and reflection (524).

526. Thus we see that light reflected from glass at 56° 45′, consists almost entirely of light polarized in one plane, equal to about one half of the whole of the incident light, and refuses to be reflected from a second glass plate when the plane of reflection is at right angles to the plane of polarization of the ray (518). Thus, as one portion of the incident light only is reflected from one plate, and that becoming absorbed when the second plate is at right angles to the first, it follows that no light ought to be reflected from this plate, if the polarization of the light be complete.

The effects thus observed of extinguishing light, by altering the position of the reflectors, are analagous to those observed by crossing two tourmaline plates. If two similar plates of that mineral be placed together, so that light polarized in one plane can be transmitted, objects may be distinctly seen through them ; but on turning one at right angles to the other, absolute darkness ensues, as each plate absorbs the light polarized in different planes. This effect may be readily understood, by fixing two gratings, TAKL (522), across each other, so that the bars of one may be vertical and those of the other horizontal, and attempting to thrust the paper figure, NSCD (522), through them. Although, when the bars of the two gratings were in the same position, one or other of the paper slips NS, CD, passes through, yet when crossed, they effectually prevent the introduction of either.

If one of the beams of polarized light obtained by double refraction (520) be used instead of the light reflected from P (524), it will present the very same phenomena on turning round the plate R, as the light polarized by reflection from P did. If light polarized by absorption of one of its component beams through tourmaline, or by its dispersion through agate (521), the same effects will be observed; so that in whatever manner light is polarized, it possesses the same properties, providing its planes of polarization (518) be in the same position.

527. It has been already stated, that part of the light refracted through glass, when incident at the polarizing angle, is partly polarized, but in a plane at right angles to the reflected beam (524). This refracted light may be obtained very free from common light (518), by placing eight plates of thin crown-glass together, and fixing them obliquely in a tube, so that they may be inclined at an angle of 79° to its long axis. On allowing a beam of light to traverse this tube, it will emerge polarized in a plane at right angles to that, at which the reflected light is under similar circumstances polarized. A system of plates thus arranged in a tube constitutes a very excellent mode of analysing light polarized by reflection, and developing the colours of doubly refracting crystals (537—546). Sir David Brewster has found, that by increasing the number of glass plates, the refracted light becomes polarized at a much smaller angle of incidence; thus, light is completely polarized by refraction through one plate of glass at an incidence of 88° 38′; through two at 87° 16′; through six at 81° 50′; through forty-one at 45°; and through 8,640,000 plates at an angle of incidence of one only second, providing

the light be of sufficient intensity to penetrate such a mass of glass.

528. If the reflecting plate P (523) were placed at any other angle except that for complete polarization, still a certain portion of the reflected light will be polarized. Very different opinions have been hazarded on the nature of this partially polarized light; it has been, by several very illustrious philosophers, considered as made up of common light (518), mixed with a small quantity of completely polarized light. Sir David Brewster, to whom science is so largely indebted for his investigations on this subject, however, considers that partially polarized, or, as he proposes to call it, apparently polarized light, is light whose planes of polarization are inclined at angles of less than 90°; and he bases this opinion on the fact that light thus partially polarized may, by a sufficient number of reflections, have its planes of polarization turned round so as to coincide, and constitute perfectly polarized light. The following table, given by Sir David,* shows the number of reflections required to completely polarize light at any angle:

Number of reflections required.	Angles at which the light is reflected.	
1	56·45	——
2	50·26	62·30
3	46·30	65·33
4	43·51	67·33
5	41·43	69·1
6	40·0	70·9
7	38·33	71·5
8	37·20	71·51

529. Sir David Brewster illustrates his position by assuming a beam of common light to be constituted as NS, CD, (fig. 1, 517). Let such a beam be incident on a reflecting surface, so that the plane of reflection exactly bisects the

* Optics, p. 173, and Phil. Trans., 1829.

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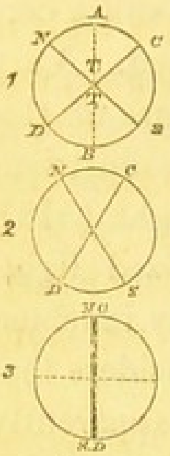
angle which the two planes of polarization form with each other, as the dotted line AB besects the angles NTC and DTS (fig. 1). By reflection from a glass-plate, whose index of refraction is 1·525, the inclination NS to AB will be 33° 13′; so that DC will describe with NS angles of 66·26, as in fig. 2. At an incidence of 65, the inclination of NS to CD will be 25° 36′; and at the polarizing angle of 56·45, the angle of inclination of NS, CD, will vanish, as the two beams are made to coincide as in fig. 3. Thus, at an incidence on glass at any angle differing from the polarizing angle of 56·45, the planes of light, NS, CD, become inclined more and more to each other, in proportion as the incident angle approaches 56·45, at which angle the two planes become so turned round as to coincide completely, and produce a single beam of polarized light.

1

2

3



530. In the preceding observations, light is supposed to be polarized by reflection from glass alone; the same physical characters may, however, be communicated to it by reflection from the surfaces of any non-metallic substance; as that reflected from metallic surfaces (553) differs in its properties from the polarized light under consideration. All bodies have their peculiar polarizing angle in the same manner as they have their index of refraction; thus, the angle for glass is 56° 45′, and for water 52° 45′. The effects of the different polarizing angles of two transparent substances upon polarized light, may be shown by an experiment described by Sir D. Brewster. Having fixed the plates PR (524, fig. 2) at the angles of 56° 45′, and with the planes of reflection and polarization perpendicular to each other, the image of the candle will be invisible in R (524). Breathe upon the latter, so as to cover it with a film of water, and immediately the candle will become visible, from a portion of the polarized beam undergoing reflection from R.

531. The angle of *complete polarization* for any substance, may be readily determined by the fact, discovered by Sir

D. Brewster, that:—*The index of refraction is the tangent of the angle of polarization.* Thus, if the polarizing angle of water, whose index of refraction is 1·336, be required, all that we have to do, is to look for that number in a table of natural tangents, or for its logarithm in a table of logarithmic tangents, and the corresponding angle of 53° 11′ will be found opposite to either. The polarizing angle of crown-glass is 56° 45′; for, as its index of refraction is 1·525, the logarithm of that number is 18327, which in the table of logarithmic tangents, corresponds very nearly to the angle mentioned.

532. Light may be polarized by reflection from the second surface of bodies, or internal reflection (448); and the angle for complete polarization has its cotangent equal to the index of refraction of the substance, and may be found by looking for the latter number in a table of cotangents. This, in the case of water, will be 36° 49′, and of crown-glass 33° 15′; so that the polarizing angle at the second surface, is equal to the complement of that for the first surface of a medium.

533. If, instead of using white light, any one of the coloured beams of the spectrum (467) be incident on a reflecting medium, it will undergo polarization in the same manner as common light, but at a different angle for each ray. The value of the polarizing angle for each, may be found from its index of refraction (445), by means of the law of tangents (531). Thus, the polarizing angle, when water is used, is 53·4 for the red, and 53·19 for the violet beams; and when plate-glass is employed, 56·34 for the red, and 56·55 for the violet.

From the data contained in Fraunhofer's table (481), the polarizing angle for each of his seven rays may be readily computed.

534. As a considerable portion of light passes through a single glass-plate and is lost (524); when the reflecting surface is composed of but one plate, too small a quantity of polarized light for many purposes is procured. The frame CD (523)

should, therefore, contain about a dozen plates of thin glass, instead of only one, and then a very powerful beam of polarized light is obtained; and whenever the Polariscope is referred to in the following pages, it is always supposed to contain these number of glass-plates in the lower frame. If light be incident obliquely on the first plate of such a series, as at an angle of 74°, the refracted light will be almost entirely polarized, and in a plane at right angles to that of the reflected beam (527). A bundle of plates of mica, or talc, may be advantageously substituted for those of glass, as they are very light, occupy but little space, and polarize light very effectually (546).

535. When the sky is tolerably free from clouds, a certain portion of the light becomes more or less polarized in its passage to the earth. The maximum of polarization takes place in a circle placed about 90° from the sun. According to Arago, the rays reflected from the moon contain a considerable portion of polarized light.

CHAPTER XXIV.

POLARIZED LIGHT.

Interference of Waves of Polarized Light, 536—*Colours produced by,* 537—*varied by revolving the Crystal,* 538—*by revolving the Analyzing Plate,* 539. *Complementary Rings in Crystals with one Axis,* 541. *Negative and Positive Systems,* 542. *Rings in Crystals with two Axes,* 543. *Complementary Tints in unannealed Glass,* 544-5. *Analyzis of Refracted Rays, by Plates of Agate, Tourmaline, Mica, or Glass,* 546. *System of Rings in Compressed Jelly,* 547—*in Crystalline Lenses,* 548. *Circular Polarization,* 549. *Circular Polarization in Organic Fluids,* 550. *Formula for Molecular Force of Rotation,* 551. *Conversion of Rectilinear into Circular Polarized Light,* 552. *Elliptic Polarization,* 553. *Dichroism exhibited by Polarized Light,* 554.

536. Having described some of the most important properties of white rectilinearly polarized light, we have next to investigate some of the phenomena of colour produced by interference. To appreciate these, the following laws, discovered by M M. Arago and Fresnel, must be previously well understood.

(A.) Two beams of light polarized in the same plane, are capable of interfering with each other like common light (486), and they produce in consequence fringes of the same character.

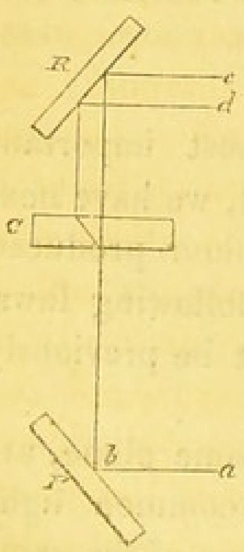
All the experiments on diffraction (489), if repeated with polarized light, will produce the same phenomena as if common light were used.

(B.) Two beams, polarized in planes at right angles to each other, will not by their interference produce colours. When polarized at angles intermediate, between 0° and 90°, they produce fringes of intermediate brightness, the tints disappearing at 90°, and recovering their vividity at 0°.

(C.) Two beams polarized at right angles, may be brought into the same plane of polarization, without acquiring the power of forming fringes by interference.

(D.) In the phenomena of interference produced by rays that have undergone double refraction, a difference of half an undulation must be allowed, as one of the beams of light is retarded to that amount by some unknown cause.

537. Interference, and consequent production of fringes, take place, when a polarized beam undergoes double refraction, providing that the plate be not so thick as to produce too great a separation of the images. Let PR be the plates of the polariscope (523), a ray of common light *ab* being incident on P will become polarized; and being reflected towards R, will enter the crystal C, and be divided into two portions, providing it traverses any part except the neutral axis (510) of the substance, forming an ordinary and extraordinary ray (507); these will impinge upon the plate R, and be reflected from thence to the eye. The rays *c d* will interfere by law A (534), and produce a coloured fringe varying in intensity with the amount of retardation experienced by one of the rays whilst in the plate C. To ascertain the real amount of retardation, we must, by law D (536), calling *d* the interval of retardation, add to it half an undulation, as one of the rays undergoes a change from the ordinary to the extraordinary state. If, other things remaining the same, the plate R be turned round a quarter of a circle, a second series of fringes or colours will be produced complementary to the first. The colours, when the plates PR are placed as in the figure, correspond to the intervals of *d* and $d + \frac{1}{2}$ undulation; whilst, after R is turned round 90°, the intervals will be *d*, and $d - \frac{1}{2}$ undulation. Thus, as the whole intervals of retardation differ by an



entire wave or undulation, the colours in the one case will be complementary to those in the other. The plate R is always termed the analyzing plate, because it analyzes and develops the light reflected from P.

538. To exhibit these tints by the interference of polarized light, place on the glass stage of the polariscope (523) a thin lamina of selenite, of uniform thickness, and allow a beam of light, polarized by reflection from the lower plate P, to pass through it to R. The source of light may be the sun's rays, or diffused daylight, or still better, the light of a lamp or candle provided with a ground-glass shade. Let the index on NM be placed at o on the graduated circle EF, by turning round the former, and the plates RP be placed as in figure 1 (524). Let R and P be fixed at the polarizing angle (531), and on looking into the analyzing plate R, the image of the selenite will be seen, not colourless, but possessing a tint varying with the thickness of the plate. Let us suppose the film of selenite is of such a thickness as to appear red when its image is viewed in the analyzing plate; slowly turn round the selenite, and the colour will gradually disappear and ultimately vanish; at this point the plane of primitive polarization (524) will pass through one of the neutral axes (510) of the selenite, and not being divided into two rays, no interference, and therefore no production of colour can ensue. Continue to turn round the selenite, and the red colour gradually reappears, attaining eventually its primitive brilliancy; on continuing the rotation, the colour again lessens, and disappears when the plane of polarization passes through the second neutral axis of the crystal. The greatest intensity of colour will be observed when one of two lines, inclined 45° to the neutral axis, lies in the plane of primitive polarization (524); these lines are termed *depolarizing axes.*

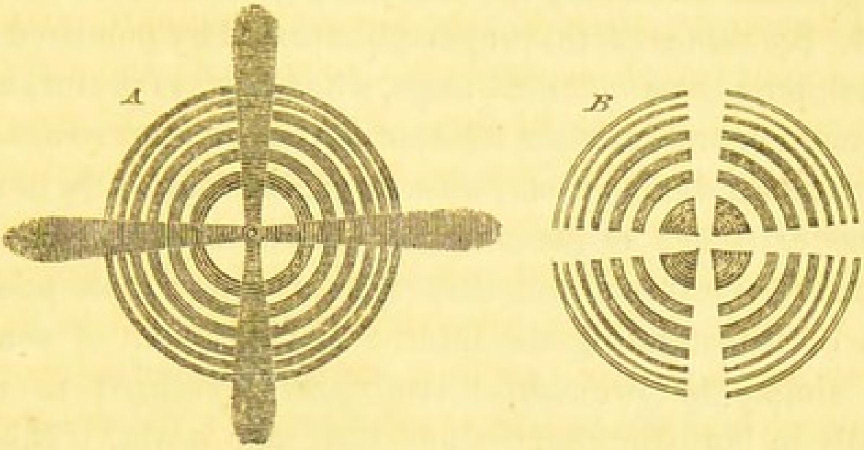
539. Having again placed the plates of the polariscope as at the commencement of the last experiment, let the film of selenite remain fixed, and when its red image is visible in the analyzing plate, slowly revolve the latter, noticing the arcs of rotation on the graduated circle. On revolving the analyz-

ing plate, the red colour of the reflected image will gradually lessen, and when a revolution through 45° has been performed, it will disappear; after 45° the film will gradually assume a green colour complementary (498) to the red; and will attain its greatest brightness at 90°. From 90° to 135° the green vanishes, and after 135° the red reappears, attaining its most vivid state at 180°, after which it again vanishes; at 270° acquiring its green colour, which, on continuing to turn the plate vanishes at 325°; ultimately becoming red at 360° or 0°, from which point we set out. If the plate of selenite had been of such a thickness as to afford other tints, the complementary colours would have appeared, as in Newton's experiments, with the colours of thin plates (497); the colours seen at 0° and at 90°, or 180°, and 270°, being invariably such as, when united together, would constitute white light.

540. If a thin plate of talc or mica, be placed on the stage of the polariscope, instead of the selenite, colours disappearing and reappearing in the same manner will be seen. And on inclining the mica, so that the polarized ray may pass through different thicknesses of it, a variety of exquisitely beautiful tints will become developed. If the mica or selenite be not of uniform thickness, the reflected image will appear richly tinted with various hues, depending for their variety and intensity upon the varying thickness of the plates.

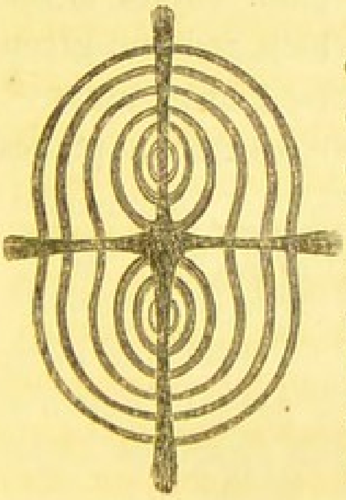
541. In the year 1813, Sir David Brewster discovered the beautiful systems of rings in topaz, ice, and numerous other crystals; to observe these in uni-axial crystals, the polarized light should be transmitted along their axes (510). If a rhomb of calcareous spar, the apices of the obtuse angles terminating whose axis are cut off, and the triangular faces thus left, polished, be placed on the glass stage of the polariscope, which for this purpose should be brought as near as possible to the analyzing plate (546), and a beam of polarized light transmitted, a beautiful series of coloured rings, intersected by a black cross, as shown at A, will appear, when the planes of the analyzing and polarizing plates are at right angles to each other (524, Fig. 2); the index on MN

(523) being at 90°. The colours of the rings are the same as



those described by Newton (498); and on turning round the analyzing plate, so that the index may be at 0° or 180°, these rings will be replaced by another set complementary to them; the black cross disappearing, and leaving white spaces in the place it previously occupied, as shown at B.

542. If polarized light be transmitted along the axis of any other crystal possessing one axis of double refraction, similar phenomena will occur, and this ensues whether the axis of double refraction be negative or positive (510). But although the rings produced by both classes of crystals resemble each other, yet they possess different properties, for on superposing two equally thick plates of a positive and negative crystal, as calcareous spar and zircon (511), no rings will be visible, although when separated each exhibits its own system.



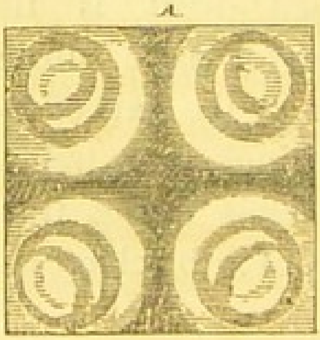
543. In crystals with two axes of double refraction, as nitre, topaz, sulphate of nickel, potassio-tartrate of soda, &c. (514), a double system of rays is visible when polarized light is transmitted through plates of these substances, cut perpendicular to the axis of the crystal. In nitre these rings are extremely beautiful, both systems being traversed by the long arm of a black cross, as in the

marginal figure; the complementary system of rings becoming visible on turning the analyzing plate round 90° (538).

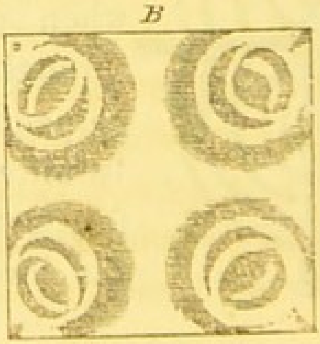
544. By means of the property possessed by polarized light of developing these coloured rings, which always in tint and arrangement bear a constant relation to the physical structure of the crystal producing them, we are enabled frequently to make out the existence of peculiar and intimate arrangement of molecular structure; and thus acquire a new and powerful mode of investigating the internal arrangement of some of those simple but wonderful structures presented to us so liberally in both the organic and inorganic world. This may be beautifully illustrated by subjecting unannealed glass to the action of polarized light; we have seen that glass, by suddenly heating or cooling, acquires the property of double refraction (516). If the glass be properly prepared, by heating it red hot, and rapidly cooling it, this doubly refracting structure is permanent. Such a piece of glass appears, when viewed by ordinary light, like any other piece; nor can any peculiar feature be detected in it, in which it differs from other specimens of that substance. But if a piece of this prepared glass be placed on the stage of the polariscope, a most beautiful coloured image will become visible in the analyzing plate; whilst, under similar circumstances, the glass before heating did not exhibit the slightest colour. Let the planes of the analysing and polarizing plates be at right angles (524, fig 2), the index being at 90, and if the glass be shaped into a cube, the beautiful figure shown at A will appear. The circular curves in the angles possess the most vivid hues, in which red and green predominate; the centre being occupied by a black cross.

On turning the analyzing plate round 90°, so that the planes

A.

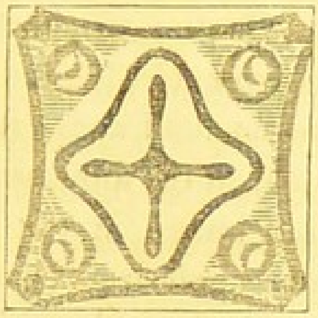
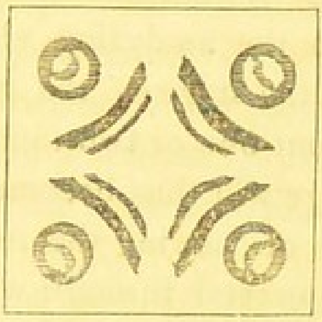


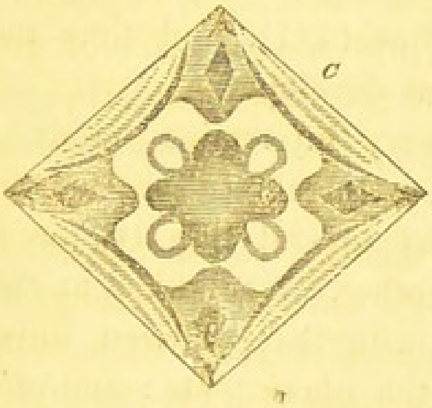
B



of reflection and polarization may coincide (524, fig. 1), the colours, which almost entirely vanish at 45°, will undergo a remarkable change; the figure shown at B will appear, all the colours of which are complementary to those of A, and the black cross will be replaced by white spaces.

545. If the plate of unannealed glass be square, and about one third as broad as it is long, the elegant figure shown at A will be visible when the analyzing plate is set at 90°, so that

A


B


C

the plane of reflection may be perpendicular to the plane of polarization. The complementary figure B, replacing it when the analyzing plate is placed at 0° or 180°, so that the planes of reflection and polarization correspond.

The dark lines forming the black cross, seen when these plates or laminæ of crystals (541, 543) are submitted to polarized light, must be considered as pointing out the position of the points where the polarized ray passes through unchanged, and are hence conveniently called *lines of no polarization.* If the analyzing plate be fixed, and the unannealed glass be slowly turned round, the black cross will begin to open, and its arms to separate in elegant curves, until its resultant axes (510) are inclined 45° to the planes of polarization and reflection (524), when a beautiful symmetrical figure will be visible, as at c in the last figure. On continuing to turn the plate of glass, the dark cross gradually re-appears, and attains its greatest intensity when one of its arms corresponds to the plane of polarization, and the other to that of reflection.

546. When the crystal submitted to polarized light is very small, both it and the eye should be placed as near as possible to the analyzing plate. Or the specimen may be placed on the stage of the polariscope (523), and a convex lens of about one or two inches focus held above it; a magnified image will thus become visible in the analyzing plate.

Instead of viewing the reflected image in the analyzing plate, the crystal through which the polarized beam is passing may be examined by looking at it through a thin plate of agate, or tourmaline (521), and thus the complementary colours will become developed.

Another, and very interesting mode of analyzing the transmitted light, is to replace the analyzing glass plate of the polariscope, by several thin laminæ of mica, or talc, placed closely together. When fixed at the polarizing angle, the usual image with the polarized tints may be seen by reflection, as in the glass plate: and on looking vertically downwards through the inclined laminæ of mica, a second image, complementary to the first, will become visible without moving the plate. If a thin piece of mica be exposed to a red heat, so as to split it into numberless laminæ, it will, as Professor Forbes has shown, render the complementary tints visible in a very beautiful manner. The eye-piece before described, consisting of six or eight plates of glass fixed diagonally in a tube (527), may be very conveniently substituted for the analyzing plates of the polariscope, in developing the tints of doubly refracting crystals. On viewing, for example, unannealed glass, when traversed by a polarized ray, by means of this eye-piece, the beautiful tints traversed by the black cross, will be seen when the plane of the glass plates in the tube corresponds to that of the polarizing plate; the complementary colours becoming visible on turning the tube round 90°, so that the plane of the inclined glass plates may be at right angles to that of the polarizing plate.

547. When a mass of animal jelly is placed on the stage of the polariscope, no colours are visible in the analyzing plate, so long as the jelly is not submitted to pressure; but as soon as it is compressed with sufficient force, it assumes a doubly refracting structure, and a series of tints traversed by a black cross becomes visible, providing the analyzing plate be so placed that the planes of reflection and polarization are at right angles.

Jelly, solutions of gum, and albuminous fluids, allowed to evaporate spontaneously, so as to leave an indurated mass, also exhibit the four coloured sectors, traversed by a black cross. A slip of glass, previously without action on polarized light, develops a series of tints, by bending it or submitting it to pressure.

548. No series of objects exhibits the tints of polarized light more beautifully than the crystalline lenses of animals, especially of fishes; to examine these they should, to prevent their bringing the incident rays to a focus, be immersed in a glass vessel containing oil, or some fluid possessing nearly the same refractive power as the lens. The crystalline lens of the cod fish exhibits twelve beautiful coloured sectors, separated by two dark concentric circles of no polarization, (545), and traversed by a black cross.

Fragments of ordinary quills, and other indurated animal structures, also exhibit these tints, when submitted to the action of polarized light, in an extremely beautiful manner.

549. When two systems of undulations of equal amplitude, and polarized in planes at right angles to each other, differ in their paths by a quarter of an undulation, the com-

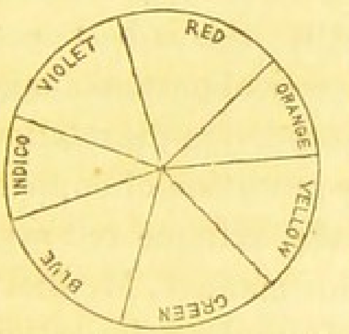
pound movement thus generated in each molecule of ether, will not be rectilinear, as in the variety of polarized light we have just examined, but circular. When the set of undulations which is in advance of the other by the fourth of an entire wave, has its plane of polarization to the right of that of the latter series, the motion will be propagated from right to left in a spiral direction, and from left to right when the systems of waves are ranged in the opposite direction. Let a thin plate of regularly crystallized quartz be cut in a direction perpendicular to its axis, and placed on the stage of the polariscope ; on looking into the analyzing plate, no black cross will be visible as in calcareous spar (541). But a few rings will be seen at the circumference of the crystal, the centre being filled up by an uniform tint, providing the plate be of the same thickness throughout, otherwise it will vary, as the intensity of colour depends on the thickness of the plate. If the central colour be red, slowly revolve the analyzing plate, and the tint will change to orange, yellow, green, and ultimately to violet; as though the analyzing plate had during its rotation acquired the power of reflecting these different colours.

In some specimens of quartz, and other crystals possessing this power of circular polarization, the colours change from red to violet, when the analyzing plate is turned from right to left, and in others when it is moved from left to right. Hence these crystals are termed right-handed, or left-handed, according as they possess the property of causing the planes of polarization to revolve spirally in a direction from right to left, or left to right.

A plate of left-handed quartz 0·3 inch thick, when placed on the stage of the polariscope, so that a polarized ray may pass through it, appears of a fine blue, when viewed through a plate of tourmaline, or bundles of mica or glass plates (546), held in such manner as to prevent the ray from being refracted through them before being transmitted through the crystal. On turning the quartz round on its axis, no change of colour ensues; but on moving the eye-piece of tourmaline, glass plates (546), &c., the following changes of colour are observed at different azimuths:

Azimuth.	Colour of transmitted Image.
0 . .	. . Fine blue
28 . .	. . Pea green
73 . .	. . Greenish yellow
98 . .	. . Tawny orange
115 . .	. . Vivid red
145 . .	. . Violet
180 . .	. . Rich blue,

The phenomena thus observed, are the same as would necessarily occur, if the polarized light had been, by passing through the quartz, resolved into a series of homogeneous rays, and become disposed in different planes radiating from the centre of a circle, as shown in the marginal figure representing Newton's chromatic circle in the circumference of which the colours of the spectrum (467) are arranged. The thicker the plate of quartz employed, the greater is the arc required to effect the conversion of the image into one of a different tint; so that, although in the above experiment a rotation of the analyzing eye-piece through an arc of 180° was sufficient to develop images possessing every colour of the spectrum (467), yet, on increasing the thickness of the plate, a much larger arc is required to produce the same effect.



To render this more intelligible, place a plate of quartz, 0·04 inches thick, on the stage of the polariscope, and allow a ray of homogeneous light (467) to fall upon the polarizing plate. If this light be red, then the space in the centre of the rings visible in the quartz will be the brightest when the index is at 90°, or when the planes of reflection and polarization are at right angles to each other. Slowly revolve the analyzing plate, and after a rotation of 17°·49, the red tint will cease to be visible; with a plate of quartz of double the thickness, a rotation of 35° will be required to produce the same effect, the amplitude of the arc of rotation increasing with the thickness of the crystal. If the light were green, a rotation of 27°·8, and if violet, of 40°·8, would be required, before the corresponding colours in the centre of the plate of quartz would vanish, providing the latter is of the uniform thickness of 0·04 inch.

550. Certain organic substances, as melted sugar, camphor, and a large number of fluids, develop the phenomena of circular polarization. If a brass tube, closed at its lower end with a plate of glass, and about six or eight inches in length, be filled with oil of turpentine, and placed on the stage of the polariscope, the richly coloured images (549), and a rotation of the plane of polarization from right to left, will be observed. The action of the oil is much less intense than that of quartz, in the proportion of 1 to 68·5; hence the necessity of using a tube full of the oil, so as to form a fluid plate about six or eight inches thick.

Some organic products turn the planes of polarization from left to right, others from right to left (459); this is best seen by using homogeneous light, which for practical purposes may be effected with sufficient accuracy, by observing the rotation through a piece of glass coloured red by protoxide of copper, and which allows scarcely any except the extreme red rays to pass through it. By operating in this manner, M. Biot* has succeeded in detecting the property of circular polarization in an immense number of fluids, and he has even applied this property to organic chemistry, as a mode of distinguishing between closely allied organic products, as the different varieties of gums and sugars. In the following table are the results of some of the most interesting results of Biot's experiments; the position of the points of the daggers in the third column indicate the direction of the rotation of the planes of polarization *observed through red glass.*

* Mém. de l'Acad. royale des Sciences de l'Institut. xiii., pp. 39. 176, *passim.*

Name of Fluid.	Arc of rotation observed through red glass.	Direction of the rotation.	Thickness of column of fluid in millimetres.	Specific gravity of the fluid.
Oil of turpentine	45°	→	152	
Oil of citron	84	←	152	
Oil of bergamotte	29	←	152	
Oil of anise	(?)	→	163	
Oil of carraway	100	←	152	
Oil of spearmint	(?)	→	152	
Oil of rue	(?)	→	152	
Naphtha	12° 40′	→	163	
Sol. of cane-sugar in water	23 5	←	152	1·1052
Ditto	51 1	←	152	1·2310
Sol. of sugar of milk in water	10 3	←	152	1·0537
Sol. of sugar of starch in water	48 5	←	152	1·2459
Syrup of grape sugar	(?)	→	152	
Sol. of mannite in water ...	insensible	(?)	152	
Grape juice	6°	→	160	
Apple juice	3 33	→	160	
Sol. of tartaric acid in its own weight of water	8 5	←	160	

551. A solution of one part of common white sugar in four parts of water was placed in a brass tube seven inches long, and 0·6 inch in diameter, closed at one end by a plate of glass; on transmitting a polarized ray through it, and analyzing the refracted light by an eye-piece of glass-plates (546), or calcareous spar (520), placed so as to reflect or disperse the ray before passing through the syrup, I found the following to be the tints of the transmitted images at different azimuths :

Azimuth.	Colour of Image.
0	Pea-green.
55	Rich blue.
80	Very dark purplish violet.
95	Bright reddish violet.
132	Fine orange.
200	Rich deep blue.

To apply the property of circular polarization to establishing distinctions between closely allied organic products, and to the detection of differences of molecular arrangement in bodies composed of the same elements in similar proportions, M. Biot has calculated the *force of molecular rotation* of several bodies. This force is nothing more than a comparative expression of the circularly polarizing powers of bodies when reduced to an unity of density and thickness; the unity of thickness assumed by M. Biot is the millimetre, equal to 0·03937, or nearly 0·04 inch. The formula deduced from these interesting researches is of great value, as affording a simple mode of discovering the molecular circularly polarizing, or rotating force, of different organic bodies; the following is its simplest expression:

The proportion of organic matter present in one part of the solution $= p$.

Specific gravity or density of the solution $= d$.
Length of the column of fluid employed $= l$.
Arc of rotation observed through red glass $= a$.
Molecular force of circular polarization $= m$.

$$m = \frac{a}{l\,p\,d}.$$

The following is an example of the application of this formula:—MM. Biot and Persoz digested 400 parts of potato starch in a mixture of 160 parts of sulphuric acid and 1000 of water, and dissolved the sugar thus generated in water. The following data were obtained:

Proportions of saccharine matter in solution, $0{\cdot}210711 = p$.
Density of the solution, $1{\cdot}08391 = d$.
Length of column of fluid employed, $152^{mm} = l$.
Arc of rotation observed through red glass, $50° = a$,

$ml = \frac{a}{pd} = \frac{50}{{\cdot}210711 \times 1{\cdot}08391} = 218{\cdot}92$ = the molecular force of circular polarization for a density of 1, and a thickness of 152; consequently $\frac{ml}{l} = \frac{218{\cdot}92}{152} = 1{\cdot}44$ = the rotating force of sugar of starch at an unity of density and thickness.

552. Rectilinear may be converted into circular polarized light, by causing it to suffer two reflections in the interior of a glass parallelopiped, at angles of 54° 30′, in a plane inclined 45° to the plane of polarization of the ray. The emergent

beam will possess all the properties of one of those produced by double refraction through rock crystal (550). M. Fresnel, to whom we owe this discovery, found that if the glass parallelopiped be sufficiently long, the beam of light will emerge circularly polarized after 2, 6, 10, 14, &c. reflections, and rectilinearly polarized after 4, 8, 12, 16, &c. reflections.* Circularly polarized light differs from the rectilinear variety, also in the colours it developes, when transmitted through laminæ of doubly refracting crystals, as selenite. The tints being always an order of colours, higher or lower, in Newton's scale (499), than those which the crystal would have produced by rectilinear polarized light.

553. If the difference of the paths of two systems of waves, instead of amounting to one fourth of an undulation (549), is a fractional number, the movement which ensues will not be circular but performed in ellipses, producing elliptic polarization. This variety of polarized light is obtained by a series of reflections from metallic surfaces, differing in number according to the metal employed; thus eight reflections from steel, and thirty-six from a surface of polished silver, are required to completely polarize a ray of common light. Elliptically polarized light may be restored to the rectilinear state, by a certain number of intermediate reflections, as in the case of circular light (552). Sir David Brewster found that at an angle of incidence of 86° on steel, light is elliptically polarized after 3, 9, 15, 21, &c. reflections, and restored to a rectilinear state after 6, 12, 18, 24, &c. reflections. Prof. Forbes has shown that when rectilinearly polarized light (517) is reflected from the surface of mica that has been exposed to a red heat, so as to acquire a silvery lustre, in such a manner that the plane of reflection is inclined to that of primitive polarization it is converted almost entirely into elliptically polarized light. This indeed

* *Vide* Sir David Brewster, in Phil. Trans. 1830, for an account of the phenomena of elliptic polarization.

constitutes the readiest mode of obtaining that modification of light.

554. A large number of crystals present different colours, according to the direction in which light is transmitted through them, constituting dichroism, a valuable sign of double refraction. An excellent example of this is met with in the chloride of palladium, which is deep red when viewed in the direction of its axis, and vivid green when examined transversely. Similar phenomena are observed in the iolite or dichroite, and many other natural and artificial substances. When such crystals are placed on the stage of the polariscope, their colours will be found to vary with the inclination of the principal section (508) to the plane of polarization. The following list contains some of the results of Sir David Brewster's researches on this subject:

Colours of the Two Images, when Crystals possessing the Property of Dichroism are submitted to Polarized Light.

Names.	Plane of Axis situate in the Plane of Polarization.	Plane of Axis at right angles to the Plane of Polarization.
	I. UNIAXIAL CRYSTALS.	
Sapphire . .	Yellowish green	Blue.
Emerald . .	Yellowish green . .	Bluish green.
Blue beryl . .	Bluish white . .	Blue.
Rock crystal .	White . . .	Faint brown.
Amethyst . .	Blue . . .	Pink.
Tourmaline .	Greenish white . .	Bluish green.
Idiocrase . .	Yellow . . .	Green.
Mellite . .	Yellow . . .	Bluish white.
Lilac apatite .	Bluish . . .	Reddish.
	II. BIAXIAL CRYSTALS.	
Topaz, blue .	White . . .	Blue.
—— green .	White . . .	Green.
—— pink .	Pink . . .	White.
Cyanite . .	White . . .	Blue.
Dichroite . .	Blue . . .	Yellowish white.
Epidote, olive-gr.	Brown . . .	Sap-green.
—— whitish-gr.	Pinkish white . .	Yellowish white.

CHAPTER XXV.

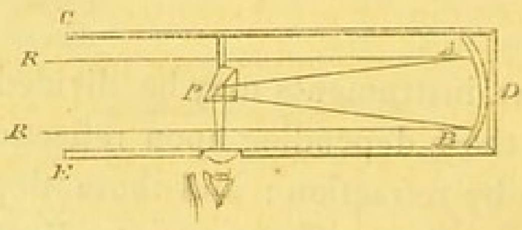
DESCRIPTION OF OPTICAL APPARATUS, AND OF THE EYE CONSIDERED AS AN OPTICAL INSTRUMENT.

Concave Mirror, 555. *Newton's Telescope*, 556. *Gregorian and Cassegrainian Telescopes*, 557. *Single Microscopes*, 558. *Camera Obscura*, 559. *Megascope*, 560. *Prismatic Camera*, 561. *Solar Microscope*, 562. *Magic Lantern*, 563. *Camera Lucida*, 564. *Wollaston and Coddington Lenses*, 565. *Compound Microscopes*, 566. *Wollaston's Doublet*, 567. *Reflecting Microscopes*, 568. *Astronomic Telescope*, 569. *Galileo's Telescope*, 570. *Chromatic Aberration*, 571. *Monochromatic Lamp*, 572. *Achromatic Lenses*, 573. *Structure of the Eye, considered as an Optical Instrument*, 574. *Action of the Eye on Light*, 575-6. *Structure of the Eye in lower Animals*, 577. *Seat of Vision*, 578. *Causes of Single Vision with Two Eyes*, 579—*of Erect Vision with an Inverted Image*, 580. *Adaptation of the Eye to different Distances*, 581. *Duration of Impressions on the Retina*, 582. *Accidental Colours*, 583-5. *Insensibility of the Eye to certain Colours*, 586.

555. Optical instruments may be divided into the *catoptric*, including those depending upon reflection; the *dioptric*, or those acting by refraction; and those depending on the combined action of both effects, or *cata-dioptric* instruments. Of optical instruments depending on reflection, the various forms of mirrors already described constitute the most important. The common looking-glass, whose theoretical action has been already explained (434), is too well known to need description; and the convex mirror, so common an ornament in large rooms, is chiefly employed on account of

the diminished images of objects which it produces, and thus the whole extent of a landscape becomes, as it were, compressed into the space of a few square inches. The concave mirror is a very important instrument, and, besides its applications to science, it forms one of the most valued resources of charlatans and jugglers, on account of the power it possesses of forming in the air an image of any object placed beyond its principal focus (441). Thus, if any object, as a dagger, strongly illuminated, be held towards a concave mirror, an image of it will be formed nearly in the conjugate focus, so vividly and perfectly painted in the air, that the person who holds the dagger can scarcely believe that the weapon which advances to meet him, is but a spectral image of the one with which he is armed.

556. The most important application of concave reflectors is to the construction of telescopes, in which the image of a distant object, as one of the celestial bodies, is formed in the principal focus of a concave mirror, and magnified by means of convex lenses (464). The simplest reflecting telescope is that constructed by Newton in 1666. This consists of a concave parabolic (466) metallic reflector AB, fixed at the end of a tube CDE. A small plane mirror (433), inclined at 45°, or, still better, a rectangular prism P, is fixed in the



tube, between the speculum AB and the image formed in its focus. The image thus becomes reflected towards the opening in the side of the tube, where it is viewed through a convex lens for the purpose of magnifying it.* The advan-

* Newton. Optice, Lib. i., prop. 8., prob. 2.

tage of a prism over a plane mirror, for the purpose of reflecting the image of the distant object towards F, is sufficiently obvious; for, by *internal* reflection (448) from the back of the prism, nearly all the rays are reflected to the eye; whereas, if a plane metallic speculum were substituted, about forty-five out of every hundred rays would be lost (431*), from the undulations producing them being checked on reaching the surface of the metal. For the purpose of preventing spherical aberration (465) from interfering with the distinctness of the images, Newton placed, between the eye and the convex lens, a plate of metal, pierced with a small hole, through which he viewed the object.

557. The Gregorian reflecting telescope was invented in 1660, by Dr. Gregory, but not actually constructed until some years subsequent to Newton's (556). In this instrument, the inconvenience of taking a lateral view is avoided. It consists of a concave speculum fixed in a tube, but pierced in the centre with a hole, through which, by means of a lens, or a combination of lenses, the image of the object is viewed. The rays forming the image of the object in Dr. Gregory's telescope are incident on a small concave mirror, and form a fresh image, which is viewed through the aperture in the centre of the large speculum. The observer, in using this telescope, is placed in a line with the object; whilst, in Newton's, he is at right angles to it (556).

When a convex mirror is substituted for the small concave one in Dr. Gregory's instrument, we have the Cassegrainian telescope. In this, the image is more distinct than in any other construction, as but one image is formed; and as one speculum is concave and the other convex, they have a tendency to correct each other's spherical aberration.

558. The number of optical instruments in which light is refracted are almost infinite, including all varieties of simple and compound microscopes, refracting telescopes, &c. The single microscope consists only of a lens, with a focal length varying according to the amplifying power required (463).

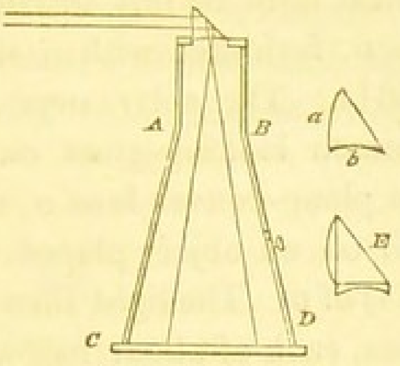
Small spheres of glass, made by fusing a filament of glass into globules, are frequently employed: their action upon light, and magnifying power will be readily understood from the remarks already made (464).

559. If, instead of permitting the image to be painted on the retina of the eye, it be received on a screen, we have a camera obscura, or solar microscope, according to the arrangement employed. If a convex lens be fixed in a hole made in one end of a box, a little longer than the focal length of the former, and painted with some black pigment, for the purpose of absorbing all extraneous light, the image of a landscape, to which the lens is presented, will be beautifully and vividly painted, in an inverted direction, on a sheet of paper fixed at the end of the box opposite to the lens. Sometimes, instead of receiving the image on a sheet of paper, it is reflected by a plane mirror, placed at an angle of 45° towards the upper or lower part of the box, a sheet of white paper being there placed to receive it. In this mode the image appears erect, and inverted only as regards the right or left portions, and is usually preferred for the purpose of sketching distant views. As the lateral portions of the picture are indistinct from spherical aberration (465), a meniscus lens is preferable to any other form of convex glass, for the purpose of reducing this serious source of incorrectness to a minimum.

560. If any small object, strongly illuminated, be placed outside of a camera obscura, and a little beyond the principal focus of the lens (456), an image of the object will be beautifully depicted on the paper screen at the end of the box. An instrument thus arranged is termed a Megascope.

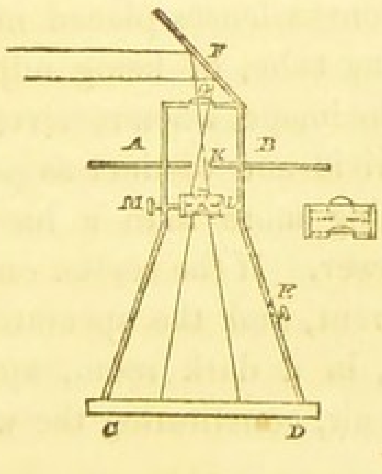
561. The best form of camera obscura is that in which internal (448) instead of specular reflection is employed, to prevent the loss of light attendant on the latter. The box is then made of a pyramidal form ABCD, and a rectangular prism, having one of its faces *a* convex, and another *b* concave, is placed over an aperture in the top of the box. The

rays from a distant object will be made to converge after



impinging on the convex surface *a*, and being reflected in the interior of the prism, will pass into the box, and paint the image on a sheet of paper placed at the bottom CD to receive it. The picture thus obtained is extremely vivid, from the perfect reflection of rays from the back of the prism, and from the spherical aberration being to a great extent counteracted by the concave face of the prism. As these meniscus prisms are difficult to procure, they may be very advantageously replaced by a rectangular prism having a plano-convex and a plano-concave lens, of proper focal length, cemented by Canada balsam on two of its faces, as shown at E.

562. When a vivid beam of light, before being made to diverge by refraction through a lens, passes through a small transparent body placed before it, an enlarged image of the object will be painted on a screen placed at a proper distance

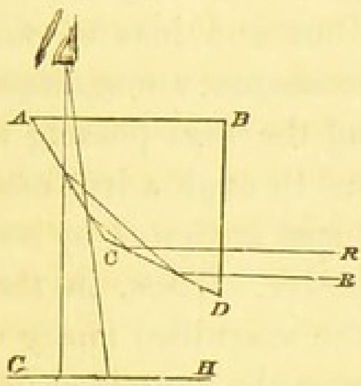


behind the lens. This is the principle of the solar microscope. The simplest form of this instrument consists of a pyramidal box ABCD, furnished with a door at E, like the camera obscura (561). The solar rays falling directly, or reflected by a common looking-glass on a plane mirror F, are reflected to the plano-convex lens G, where they undergo refraction, and fall on an object placed at K, nearly in the principal focus (453) of G. The light then passes through two plano-convex lenses, each of about half an inch focal length, at L, moveable by means of rackwork at M, and forming a widely diverging beam, paints an enormously magnified image of the object at the bottom of the box, where it may be viewed through the door E. To prevent, as much as possible, spherical aberration (320), a diaphragm of metal, pierced with a small hole, should be placed between the two lenses at L.

If the mirror F be removed, and the direct light of an Argand lamp be incident on G, we have the lucernal, and if the light of mixed oxygen and hydrogen gases be employed, we have the oxy-hydrogen microscope.

563. The magic lantern differs scarcely at all in principle from the three last-described instruments. The light of a lamp, placed in a tin or wooden box, is reflected by means of a concave mirror, or condensed by a lens, on figures painted in vivid transparent colours on slides of glass; the light is then converted into a large diverging beam by refraction through two convex lenses placed near the objects, and capable, by a sliding tube, of being adjusted to such a distance as to cause the image, when received on a white opaque screen, to be as vivid and distinct as possible; the magic-lantern being nothing more than a lucernal microscope of low magnifying power. If the screen on which the object is painted be transparent, and the spectator be placed behind it, the image will, in a dark room, appear to be painted spectre-like in the air, constituting the well-known phantasmagoria.

564. A very valuable instrument, termed the camera lucida, for taking drawings of landscapes, &c., depending upon internal reflection, was contrived by Dr. Wollaston, in 1807. This consists of a quadrangular prism, the angle

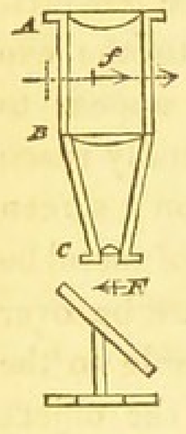


B being 90°, D 67·5°, and C 135°. Rays RR, evolved from any distant object, will, after incidence on CD, be reflected in the interior of the glass to CA, and thence to the eye placed above the angle A. And as all objects appear to be placed in the direction of the rays which eventually reach the eye (451), the image will appear to be painted on a screen or sheet of paper at GH; and if a perforated piece of metal be placed on AB, so that one half only of the aperture be over the angle A, the image and paper will both be visible to the eye placed over the aperture; and a sketch of the object may thus be taken with extreme accuracy, by simply copying the outlines of the figure seen depicted on GH.

565. When simple lenses are used for simple microscopes it is important to diminish spherical aberration as much as possible, by permitting only those rays which pass near the centre of the glass to reach the eye. This may, to a great extent, be effected by Dr. Wollaston's method, by placing between two plano-convex lenses, a piece of metal perforated in the centre. A better mode of obtaining the same effect is by grinding away the equatorial portions of a spherical lens, as in the well-known Coddington

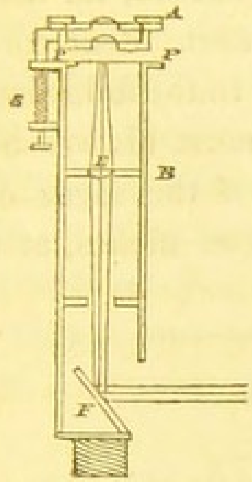
lens, which is the most perfect of any hitherto constructed.

566. Microscopes composed of two, or several lenses are termed compound, and are preferred to the simple instrument (558), from their larger field of view, and their not, when properly constructed, fatiguing the eye so much as those composed of but one lens of very short focal distance. In these microscopes, a magnified image of an object is formed, by allowing the rays passing through, or reflected from it, to be refracted through a lens of short focal distance; the image thus produced is viewed by a second lens of much lower magnifying power. Thus, in the compound microscope, we examine the magnified image of the object, whilst in the single instrument the magnified object itself is seen; and hence the former requires excessive care in their construction, to ensure an accurate and perfect image. If ABC be



a tube of brass, blackened inside to absorb superfluous light, and provided with a small lens at C, an object placed in its focus at F, strongly illuminated by light reflected from a mirror placed below it, will have an image of it formed in the focus of the eye-glass A at *f*, and may be viewed through A, by which the diverging rays are made to enter the eye in a parallel direction. For the purpose of increasing the field of view, a third lens B is often introduced; this causes the diverging rays going to form the image to diverge still more, and a larger image, as shown by the dotted lines, is formed at *f*. The distance at which the object glass C is from the eye-glass A must always exceed the sums of their focal lengths.

567. The most valuable microscope for a certain class of objects, on account of the great distinctness of the image, is the doublet of Dr. Wollaston. This consists of two small plano-convex lenses, whose focal lengths are as 1 to 3 fixed in the brass cups A, the least convex lens being nearest the eye. The brass tube B is about six inches long, furnished



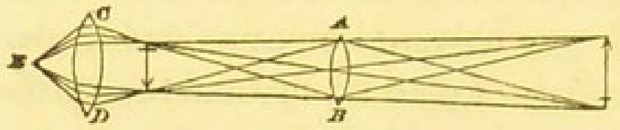
below with a plane mirror at F; a circular aperture is made in a piece of brass placed above it, through which the light reflected from F passes to undergo refraction through the convex lens E, so as to form a distinct circular image of the aperture at the distance of about 0·8 inch from E. The object to be examined is placed on a slip of glass on PP, and the lenses in A are adjusted by means of a screw at S. By this instrument, the most delicate markings and finest striæ on very minute objects, are clearly and distinctly seen.

In all compound microscopes, the centre and edges of the magnified image are never equally distinct, from the spherical aberration of the lenses (465). To remedy this, diaphragms perforated in the centre are placed in the body of the microscope, to exclude those rays which are refracted from the edges of the lenses. Menisci (459), or the compound lenses contrived by Sir John Herschel, may be used for eye-glasses, so as to prevent this aberration from interfering with the distinctness of the image.

568. Reflecting microscopes, on the same principle as Newton's telescope (556), have been constructed by Professor Amici of Modena, and others. In these instruments, the object is placed in one focus of a small and finely polished ellipsoidal speculum, and its image formed in the other focus is examined by means of a magnifying eye-piece, consisting of one or more lenses.

569. The refracting telescope was invented in the thirteenth century, although the discovery appears to have been nearly lost until the sixteenth. The simplest telescope is that employed for astronomical purposes, and consists of a convex lens of long focal distance fixed at one end of a tube, and exposed to the object, the image of which, when formed in the focus of the lens, is examined by a second convex lens,

or eye-glass, of shorter focus. These lenses should, for distant objects, be placed at a distance from each other corresponding to the sum of their focal lengths. In the following figure AB is the object-glass, and CD, which must always be of shorter focus, the eye-glass, and placed, if the focus of the former were eight, and that of the latter two inches, at a



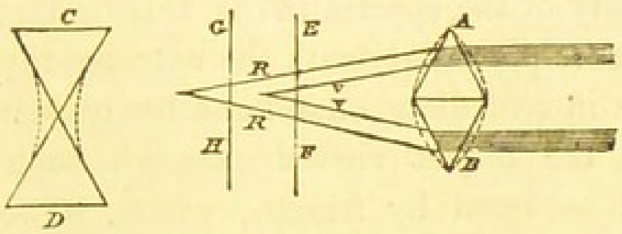
mutual distance of ten inches. To accommodate this instrument to objects at different distances, the eye-glass is usually fixed in a tube which slides within that containing the object-glass, and thus permits a ready adjustment of the instruments. In this telescope, the object appears inverted from the intersection of the rays by refraction, and hence its use is extremely limited. An erect image may be obtained by adding two other convex lenses behind CD, and of the same focal length, but a loss of light is necessarily produced by their use. Spherical aberration may be prevented as much as possible, by the same means as in the case of compound microscopes (367).

The magnifying power of these telescopes is found by dividing the focal length of the object-glass by that of the eye-glass.

570. If a concave eye-glass be substituted for the lens CD in the last-described instrument, we have the Galilæan telescope, which exhibits objects in an erect position and with very great clearness. The lenses in this instrument are placed at a mutual distance, equal to the *difference* of their focal lengths, and hence telescopes on this construction are much shorter than in those in which both lenses are convex. The magnifying power of this telescope is found by the same rule as that already given for the astronomical telescope (569). It is chiefly limited to the construction of opera glasses.

571. When light passes through a prism, it becomes re-

solved into a series of coloured rays, of which the most refrangible become bent towards the thick part of the refractor (467); but when it passes through lenses, an analagous resolution into coloured rays is not so readily observed, although it does exist, and to so great a degree as to interfere most seriously with the perfection of microscopes and telescopes, causing the image to be tinted with various colours, and producing *chromatic aberration.* The section of a convex lens may be represented by two prisms AB,



placed base to base, and that of a concave by two others CD, with their apices in contact. On a ray of light being incident upon such elementary prisms, it undergoes refraction and resolution into coloured rays; and the most refrangible, or violet VV, are brought to a focus nearer the lens, and the least refrangible, or red (469) RR, to one at a greater distance; so that, on placing a piece of paper at EF, the image of the sun or other luminous body will be seen surrounded by a violet or a purple border, which will be replaced by a red one on moving the paper to GH.

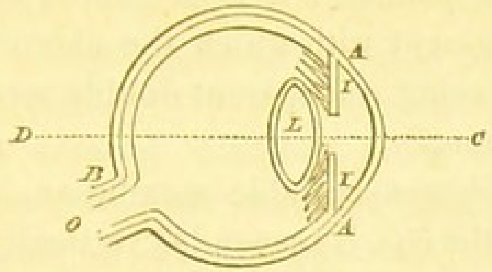
572. Chromatic aberration may in the case of the microscope be prevented, by illuminating the object with homogeneous light, as by Sir David Brewster's mono-chromatic lamp, consisting of a spirit lamp, whose wick has been soaked in strong brine, and the flame allowed to play on a mass of common salt placed above it: a lamp thus constructed discharges a pure homogeneous yellow light (480). In the telescope a similar effect might be obtained, by using a properly coloured object-glass; but this would be attended by a loss of illumination from absorption of light (475).

573. The greatest improvement ever made in optical instruments consists in the discovery of achromatic lenses:

these are formed by combining a concave and a convex lens, constructed of substances of different dispersive powers (476). Thus, if a convex lens made of crown-glass, whose dispersive power is 0·036, be combined with a concave lens of flint glass, whose power of dispersion is 0·0393, a compound lens will be constructed capable of refracting white light to a colourless focus. This combination would be perfect, if the coloured bands produced by prisms of these two glasses were of equal breadth; but, in consequence of the irrationality of the spectra (478), this perfect neutralization of tint takes place only with the extreme rays, the violet and red; the intermediate ones imperfectly destroying each other, cause the object viewed through such compound lenses to be bordered by fringes, which, however, are so faint, that for all ordinary purposes the combination may be considered as achromatic. By employing certain fluids, as hydrochloric acid confined between two lenses of crown glass, Dr. Blair overcame this remaining difficulty, and obtained a compound lens, perfectly achromatic for the intermediate as for the extreme rays.*

574. Having reviewed the theoretical construction of some of the most important instruments used for optical investigations, the student will be enabled, from the preceding observations, to understand the mode in which the eye acts upon light, so as to prepare it for communicating to the sensorium the images of objects by which we are surrounded, and thus to produce the sense of sight. The following observations, it must be borne in mind, apply only to the eye, considered as an optical instrument of the most perfect kind, and unconnected with the physiological relations of the subject, except such as are essential to a knowledge of the physical action of the organ of vision. The following figure represents a transverse section of the left eye (human), made by passing a plane through it, parallel to the opening of the

* See Sir David Brewster's Treatise on Philosophical Instruments. Edinburgh, 1813.



eyelids. The form of the eye is nearly spherical, four fifths of its circumference ABA being nearly circular, the remaining fifth AA constituting the transparent portion, being more convex, and forming a curve of a lesser sphere. After removing the muscles attached to the eyeball, the most external coat becomes visible. This is a tough, pearly opaque membrane, termed the *sclerotic* coat, extending from the entrance of the optic nerve O, on the nasal side of the optic axis CD to AA, where it terminates in a circular opening, furnished at its margin with a grooved edge, into which fits the *transparent cornea*, in the same manner as a watch-glass fits into the grooved circular piece of metal made to receive it. The cornea is as transparent as glass, and is about one third of a line in thickness. A delicate mucous membrane, or rather *epithelium*, termed the *conjunctiva*, is expanded over the cornea and sclerotic, and thence reflected to the inner surface of the eyelids. Lining the sclerotic coat is the *choroid* membrane extending from O, to the anterior part of the eye contiguous to the margin of the cornea, where it terminates in the *ciliary ligament*, constituting a bond of union between the choroid, sclerotic, and iris. The choroid being here thrown into a number of puckered folds, the interior surfaces of which, as well as of the whole extent of the membrane, are covered with a black pigment. The optic nerve O enters the eye on the nasal side of the optic axis, and expands into a third coat termed the *retina*, which passes towards the anterior part of the eye, and terminates in a well-defined edge. The retina is the membrane upon which the images formed by the refracting structures of the eye become painted: it is prevented becoming stained by the black pigment with which the choroid is imbued, by a delicate intervening transparent double membrane, termed Jacob's membrane.

A delicate fibrous irritable membrane, named from its various colours the *iris*, is suspended vertically from the ciliary ligament, having in the centre an aperture, termed the pupil, which is capable of becoming enlarged or diminished involuntarily, under the stimulus of light. The iris is shown in the section at II; the space between it and the cornea is termed the anterior chamber of the eye, and is filled with a fluid known as the aqueous humour. Behind the iris is suspended in a capsule a transparent double convex lens L, whose posterior is greater than its anterior convexity: this is termed the crystalline lens. The remaining portion of the ball of the eye is filled up by a refracting structure, termed the vitreous humour, in the anterior portions of which the lens L is imbedded: this is made up of a fluid contained in the convoluted folds of a transparent hyaloid membrane. The total length of the eye, along the optic axis CD, is about 0·91 of an inch.

575. From the investigations of Sir David Brewster, the following are the refractive indices (445) of the different refracting structures of the eye, when light is incident upon them from air, as from each other:

Ref. Index for light, passing from air into the aqueous humour	1·3366
. . . . . . vitreous humour	1·3394
Mean ref. Index for light, passing from air into the crystalline lens	1·3839
. . . . . aqueous humour to ditto	1·0353
. . . . . vitreous humour to ditto	1·0332

Rays of light, on impinging upon the eye, are refracted through the transparent cornea, those incident on the sclerotic being reflected. The cornea may be regarded as constituting the anterior surface of a meniscus lens (459), of which the posterior surface is formed by the capsule of the crystalline lens, the aqueous humour forming the refracting medium of this fluid refractor. The rays of light which thus tend to be refracted to a focus, pass through the pupillary opening of the iris, those passing too near the margin of the lens formed by the anterior chamber (574), being reflected or absorbed; the iris, answering the purpose of the perforated diaphragms in microscopes and telescopes (567), and being capable of varying its aperture, possesses advantages altogether unattainable in metallic diaphragms. The pencil of rays having passed through the fluid meniscus, impinge on the crystalline lens, and become considerably refracted; this refraction being increased by the action of the vitreous humour, the last medium into which it passes; and finally paints upon the retina an inverted image of the object, from which the luminous undulation producing the rays were propagated. All rays which are reflected in the interior of the eye, or pass too obliquely for distinct vision, have their undulations checked by the black pigment with which the choroid coat and its folds are imbued.

576. The refracting structures of the eye thus act upon light, and produce an image of any object upon the retina in the same manner as a convex lens does (461), with the advantage of increased clearness of the picture from the absence of spherical aberration (465), produced by the curved form of the retina, and by the structure of the crystalline lens; the refractive power of its centre being greater than that of its surface, in the ratio of 1·3990 to 1·3767. This diminution of aberration is also assisted by the pupil, which acts in the same manner in preventing spherical aberration, by being placed between the fluid meniscus and the crystalline convex lens, as does the perforated diaphragm in Dr. Wollaston's, or the excavated sides in Coddington's lenses (565). Chromatic aberration (571) is, doubtless, to a certain extent, compensated in the eye, by the different dispersive powers (476) of its several structures; although this organ is by no means perfectly achromatic, as may be shown by the spectral colours observed fringing minute bodies held near the eye. Nor is this achromatic state necessary for the

perfection of vision, as the deviation of the different coloured rays is too slight to produce any degree of indistinctness.

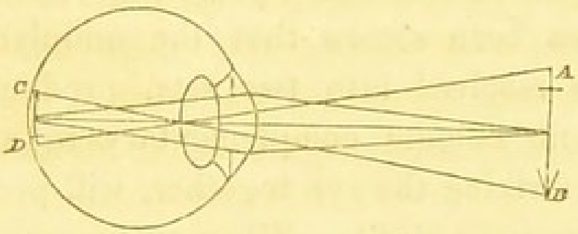
577. The eye in all warm-blooded animals is formed upon the type of that of man, with the occasional addition of supplementary portions, better fitting the organ for the performance of vision in the particular animal. In fishes, residing in a medium of nearly the same refractive index as the aqueous humour, the latter fluid becomes useless, and is replaced by a viscid secretion of greater refractive power. The crystalline lens is, in these animals, nearly spherical, and placed close behind cornea, and the iris which is close to the latter is undilatable. In insects the eye is very simple, consisting of a lenticular cornea, placed in front of a nervous expansion.

578. Although it is demonstrable that images of external objects are formed upon the retina, it is by no means so certain that the latter membrane is the seat of vision, as in certain species of cuttle-fish an opaque membrane is found between the vitreous humour and retina. The choroid coat and vitreous humour have each been supposed to be the true seat of vision. It is a curious fact, that the point where the optic nerve enters the eye is absolutely incapable of distinct vision, and if the image of any object falls upon it, it ceases to be visible. This may be shown by placing three wafers on the table about two inches distant from each other, and, having closed one eye, look at the outside wafer on the same side as the closed eye: at the distance of about eight or ten inches from it, the two outer wafers will be distinctly seen, whilst the middle one will be quite invisible. It appears from this experiment, that if vision really depends upon some vibratory movement excited in the membrane, on which the images of objects become depicted, the reason why the base of the optic nerve is insensible, is that it is too dense to assume those movements which its expansion, the retina, have readily communicated to it.

579. When an object is viewed with both eyes in a healthy person, it appears single, whilst it is obvious that a dis-

tinct image is painted upon each retina. This is readily explained by the fact, that the two images lying exactly in the direction of the optic axis, overlap each other, and virtually produce but one image. If one eye be pushed out of the optic axis, these images are separated, and then, as in the case of squinting persons, the object appears double.

580. Much unnecessary argument has been used to explain why objects appear erect, whilst their images painted upon the retina are inverted, although a little reflection on this circumstance would have shown that such must necessarily have occurred, from the law that all objects appear to be placed in the direction pursued by the rays which eventually reach the eye (434, 451). If AB be an object from which the rays following the direction of the lines shown in the figure pass into the eye, they become re-



fracted towards the retina, and paint upon it the image CD. Then if the retina be supposed to be the seat of vision, the impression communicated by it to the sensorium is that of an erect object; for the part D of the image will appear to be placed in the direction of the rays DA, and the upper part C will appear to correspond with the lower part B of the object, which will appear to be situated in the direction of the rays CB. Consequently, although the image painted upon the retina is really inverted, it conveys to the mind the sensation of an erect object.

581. The really most marvellous subject connected with the eye, as an optical instrument, is its power of adapting itself to various distances; for it is well known, that in viewing objects through a telescope, the distance of lenses from each other in the latter, requires to be altered by drawing out or thrusting in the slides of the telescope (569), whereas the

eye appears intuitively to accommodate itself to the various distances at which objects happen to be placed. Whether this is effected by an alteration in the form of the entire eye by the action of its muscles, or of the crystalline lens only, appears to be a matter of doubt; the alteration in the pupillary opening could only very slightly assist in obtaining this end, unless this is accompanied, as is very probable, by a partial displacement of the crystalline lens.

582. The impression of an object upon the retina lasts for an appreciable time after the former is withdrawn, and hence the eye may be rapidly closed and opened without losing sight of an object. If a burning coal or red hot bar be made to revolve so rapidly, that the whole revolution may be completed in about 7‴, an entire luminous circle is produced. The impression thus vividly excited upon the retina appears to continue about one-seventh part of a second of time.

583. It has been shown that the undulations of white light may be resolved into two sets, producing upon the retina different colours complementary to each other, or which, when striking the eye together, will produce the sensation of white light (498). When any person gazes upon a *red* wafer, strongly illuminated, for some seconds, and then suddenly turns the eye to a white surface near it, a spectral image of the wafer, but of a *green* colour, will become visible. If the wafer were yellow, and placed on a black surface, the spectral image will be deep violet when viewed on a white ground; in the same manner a white wafer is attended by its black spectral figure. Thus wafers, or other coloured objects produce spectra of colours complementary to their own (498). The complementary tints thus produced are termed accidental colours, and may be found by reference to Newton's experiments on thin plates (497), the reflected and transmitted rings being complementary to each other.

584. These accidental tints have been very satisfactorily explained by Sir David Brewster, in the following manner:—The eye being strongly excited by gazing on a coloured body, as a red wafer, becomes partially paralyzed

to the action of undulations producing that tint; and on then allowing white light to impinge upon the eye, those undulations, which move with such a velocity as to produce upon an unexcited eye the sensation of a colour corresponding to that of the wafer, are without action on the partially paralyzed organ; and the remaining set of undulations are alone active, producing on the retina the sensation of a tint complementary to that of the wafer.

585. A remarkable case of resolution of white light into its complementary tints, by unequally exciting the eyes with white light, has been described by Mr. Smith.* If we hold a slender slip of white paper vertically about a foot from the eyes, fixing both the latter upon an object at some distance beyond it, so as to see the paper double, and allow the light of a candle to act vividly on the right eye, without affecting the left, the left-hand image of the strip of paper will appear to be bright green, whilst the other will exhibit the complementary colour, or red. If the direction of the source of light be changed, the position of the complementary tints will become reversed.

586. Individuals are not unfrequently met with, whose eyes are as insensible to certain tints, as the ears of some are to particular sounds. Several cases of this kind have been described, in which the following colours have been confounded by the persons affected with this curious defect of the visual organs:†

Bright green, with grayish-brown and flesh-red,
Rose red, with green and gray,
Scarlet, with dark green and hair-brown,
Sky-blue, with grayish-blue and lilac-gray,
Brownish-yellow, with yellowish-brown and grass-green,
Brick-red and rust-brown, with deep olive-green,
Dark violet, with deep blue.

* Edin. Journ. Science, iii., p. 1.
† Seebeck in Poggendorff, Annalen, xlii., 177.

This remarkable state occasionally occurs in disease, and disappears on the patient's recovery. I had very lately a patient affected with cerebral disease under my care, in whom vision was previously perfect, but during the attack she confounded several tints with each other. The colours mistaken for each other in this instance were in general the complementary ones; red being mistaken for green, and orange being confounded with blue. Of the physical cause of this remarkable state, however, nothing is known.

NOTE.

In the elaborate Monograph on Light in the Cyclopædia Metropolitana, by Sir John Herschel, the student will find a most valuable source of reference for everything connected with physical optics. The Essay on Optics by Sir David Brewster, in Lardner's Cyclopædia, will prove a most excellent guide for the less advanced student.

For further information on the subjects treated of in the last six chapters, in addition to the general treatises on physics before referred to, the reader should consult the Treatise on Optics by Sir Isaac Newton, the Essay on Optics by the late Dr. Wood, of Cambridge, and Dr. Young's Elements of Natural Philosophy. In the researches of Sir David Brewster on polarized light, diffused through a series of papers in the Transactions of the Royal Societies of London and Edinburgh, will be found every information on that interesting department of physics.

ALPHABETICAL INDEX.

The Figures refer to the Pages.

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PRINTED BY C. ADLARD, BARTHOLOMEW CLOSE.